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Soil Carbon Sequestration Under Bioenergy Crops in Poland

Magdalena Borzecka-Walker, Antoni Faber, Katarzyna Mizak, Rafal Pudelko and Alina Syp
Institute of Soil Science and Plant Cultivation-State Research Institute Poland

1. Introduction

Agriculture practices have an important role to play in mitigating climate change due to atmospheric enrichment of carbon dioxide, and other greenhouse gases (GHG). Land management can strongly influence soil carbon stocks and careful management can be used to sequestered soil carbon. It is important to propose contemporary management practises to farming, like the conversion from a tillage system to no-tillage, incorporation of cover crops and forages in the crop rotation, use of crop residues and biosolids e.g. mulch, implementation of biocrops, as well as integrated nutrient management which including compost/manures as well as the precision use of fertilizers and integrated pest management. Sustainable management in agriculture should reduce and avoid the introduction of carbon dioxide (CO_2) to the atmosphere, which is one of three most prevalent GHGs directly emitted by human activity. CO_2 is the most important anthropogenic GHG, and according to IPCC Fourth Assessment Report (2007), anthropogenic CO_2 emissions grew by about 80% between 1970 and 2004. Carbon sequestration is a process through which agricultural and forestry practices remove carbon dioxide (CO_2) from the atmosphere into a form that does not affect atmospheric chemistry (Lal, 2004a). A natural way to trap atmospheric CO_2 is by photosynthesis, where carbon dioxide is absorbed by plants and turned into carbon compounds, stored or fixed C as soil organic carbon (SOC). The SOC pool consist litter, humads and humus, which it is comprised of mixtures of plant and animal residues at various stages of decomposition along with microbial by-products (Lal, 2004a). Agriculture is responsible for 13.5% of global anthropogenic GHG emissions (IPCC, 2007), but if sustainable land management practices are implemented, agricultural soils could become a carbon sink (Dumanski et al., 1998). There are five principal global carbon pools. The oceanic pool (38 Gt) is the largest, followed by the geologic (5 Gt), pedologic (2.5 Gt), biotic (0.56 Gt), and the atmospheric pool (0.76 Gt). The soils beneath the oceans are the most important reservoir of carbon in the terrestrial biosphere and contain three times the amount as compared with those that are found in vegetation (Lal, 2004b; SEC, 2009). Soils contain more than twice the carbon that can be found in the atmosphere and the loss of carbon from soils can have a significant effect on atmospheric CO_2 concentrations, which can influence the climate (Smith, 2008). Many studies have examined the sequestration potential in agriculture and forestry in Europe (Smith et al., 1997; Smith et al., 2000; Vleeshouwers & Verhagen, 2002; Freibauer et al., 2004;

Smith, 2004;) and globally (Smith 2004; IPCC 2007; Lal, 2004a), as well as in other regions of the world such as North America (Dumanski et al., 1998; Franzluebbers & Follett, 2005) or Africa (Ringius, 2002). The potential for carbon sequestration in the European Union (EU) is approximately 90–120 Mt C/y, in the US cropland is 75–208 Mt C/y, in Canada is approximately 24 Mt C/y, to obtain this potential, optimal land management practices have to be implemented (Hutchinson et al., 2007). It is estimated that the global potential scale of carbon sequestration in soils used for agricultural purposes is around 0.3 t C/ha/y on arable lands, and around 0.5 – 0.7 t C/ha/y on grasslands (IPCC, 2000). The conducted researches indicate existence of a high potential for carbon sequestration in soils under agricultural crops. Depending on the used method for its evaluation and it range between from 0.15-0.22 t C/ha/y for willow (Bradley & King, 2004) up to 0.93 t C/ha/y for Miscanthus (Matthews & Grogan 2001). The net soil carbon sequestration simulated for biocrops in Poland was around 0.38 – 0.95 t C/ha/y Miscanthus crops and 0.22 – 0.39 t C/ha/y for willow coppice (Borzecka-Walker et al., 2008).

There are many policies, directives, standards, as well as norms in the EU designed to stimulate and support the reduction of GHG emission and to improve the carbon mitigation potential. The publication of a Green paper "Towards a European strategy for the security of energy supply" (2000) started a debate on energy security, which is considered a key element of politico-economic independence of the EU. It stressed the need to improve the organisation's strategic stocks of raw materials and coordinate its use. Additionally, the European Commission presented a White Paper that sets out the actions necessary to strengthen the Union's ability to adapt to a changing climate. To support the biofuels industry, the Energy Taxation Directive allows exemptions or reductions from energy taxation for biofuels (Directive, 2003/96/EC). The aims of the recently released European Parliament and the Council directive on the promotion of the use of energy from renewable sources amending and subsequently repealed Directives 2001/77/EC and 2003/30/EC (Directive 2009/28/EC); are to achieve by 2020 a 20% share of energy from renewable sources in the EU's final consumption of energy and a 10% share of energy from renewable sources in each member state's transport energy consumption. Moreover the GHG emission saving from the use of biofules and bioliguids shall be at least 35%, 50% in 2017 and 60% in 2018 yrs.

The aim of this review is an evaluation into the current knowledge of carbon sequestration and to present potential bioenergy crops for carbon sequestration in Poland.

2. The soil's organic matter balance

There are several methods and simulation models useful for defining the content of soil organic matter. The following work will present two methods which were applied for the Polish territory. It should be stressed that the results obtained by using both methods are comparable. Based on these results, it can be concluded that the coefficient method used in the assessment of carbon balance has a small error and gives equally reliable results as while using the soil profiles method.

2.1 The soil's organic matter balance based on the determination of soil profiles

The content of organic matter in soils of agricultural land is highly variable. The results of determinations carried out in Poland show that it varies in the arable layer within the limits of 0.5-10% with an average of 2.2%. According to the division used in Polish soil with low humus content (<1%) account for approximately 6% of agricultural land, the average (1.1-2.0%), approximately 50% of the area, but about the content > 2% of approximately 33%. The global balance of organic matter in Polish soils is negative in all regions (-0.06 to - 1.05 t C/ha/y), with the average for the country of -0.47 t C/ ha/y. This means that in large areas of Poland we note the CO_2 emissions from soil to the atmosphere (Terelak et al., 2001; Stuczynski et al., 2007). In the years 2000-2004, a preliminary analysis of soil humus content trends were carried out under repeated testing of standard profiles. Studies have shown a significant decline in humus, mainly in soils initially rich in organic matter. A decline in soil organic matter is associated with the change of soil water relations, i.e. more intensive use and drainage. In contrast, a large part of the light soils of the last 30 years recorded an increase of humus content associated with an increased level of fertilization and increase in quantity of crop residues (Stuczynski et al., 2007). Based on measurements taken in the years 1968-1983 and in 2003, the changes in soil organic matter and humus loss risk were able to be calculated. The results presented in figure 1 show both accumulation and humus loss in soil as well as soil organic matter balance. The highest losses of soil organic matter were calculated for the Kujawsko-pomorskie voivodeship, whilst the lowest was in the Malopolskie voivodeship. Voivodeships of the North Western part of the country have the lowest soil organic balance, and this indicates a greater share of soils with a higher risk of loss of function due to mineralisation of soil humus.

2.2 The soils organic matter balance based on coefficients

The amount of organic matter in soils is a key indicator for the quality, and is significant for their physicochemical properties such as sorption. Maintaining high humus content in soil is important because of its impact on soil carbon sequestration. Increasingly popular intensive use of soils, combined with a simplified crop rotation, increased predominance of cereal plants with reduced amounts of livestock, leads to a reduction in the amount of organic residues entering the soil, which in turn leads to reduced carbon sequestration in soil.

The basic principle of good farm management is to maintain a positive, or at least a sustainable balance of soil organic matter. This balance can be obtained by the selection of species of cultivation plants, their participation in the crop structure, and the quantity of manure and organic. The various species of crops leave different amounts of crop residue. The soil carbon in cropland can be increased by planting more forages, and increasing residue inputs from plants with high biomass potential. Approximately, it can be concluded that the weight of cereal crop residues is about 3-fold greater than the root, and legumes with grasses, by up to 6-fold. In addition, a different duration and degree of shading the soil surface and the number of tillage performed and care, which affects the mineralisation of humus.

The cultivated plants can be separated in three groups depending of the impact on the balance of humus in the soil.

The first group includes plants with a potential in enriching the soil with organic matter. Among them are primarily long-term forage legumes and their mixtures with grasses and grasses grown in the field as well as crops grown for energy sources like tall grasses, fast growing trees. In addition, legumes and intercrops ploughed as green fertilizers have little positive effect on the balance of humus. The reproduction rate of soil for this group of plants ranges from 0.21 to 2.10, depending on the type of soil they are grown on (Fotyma & Mercik, 1992).

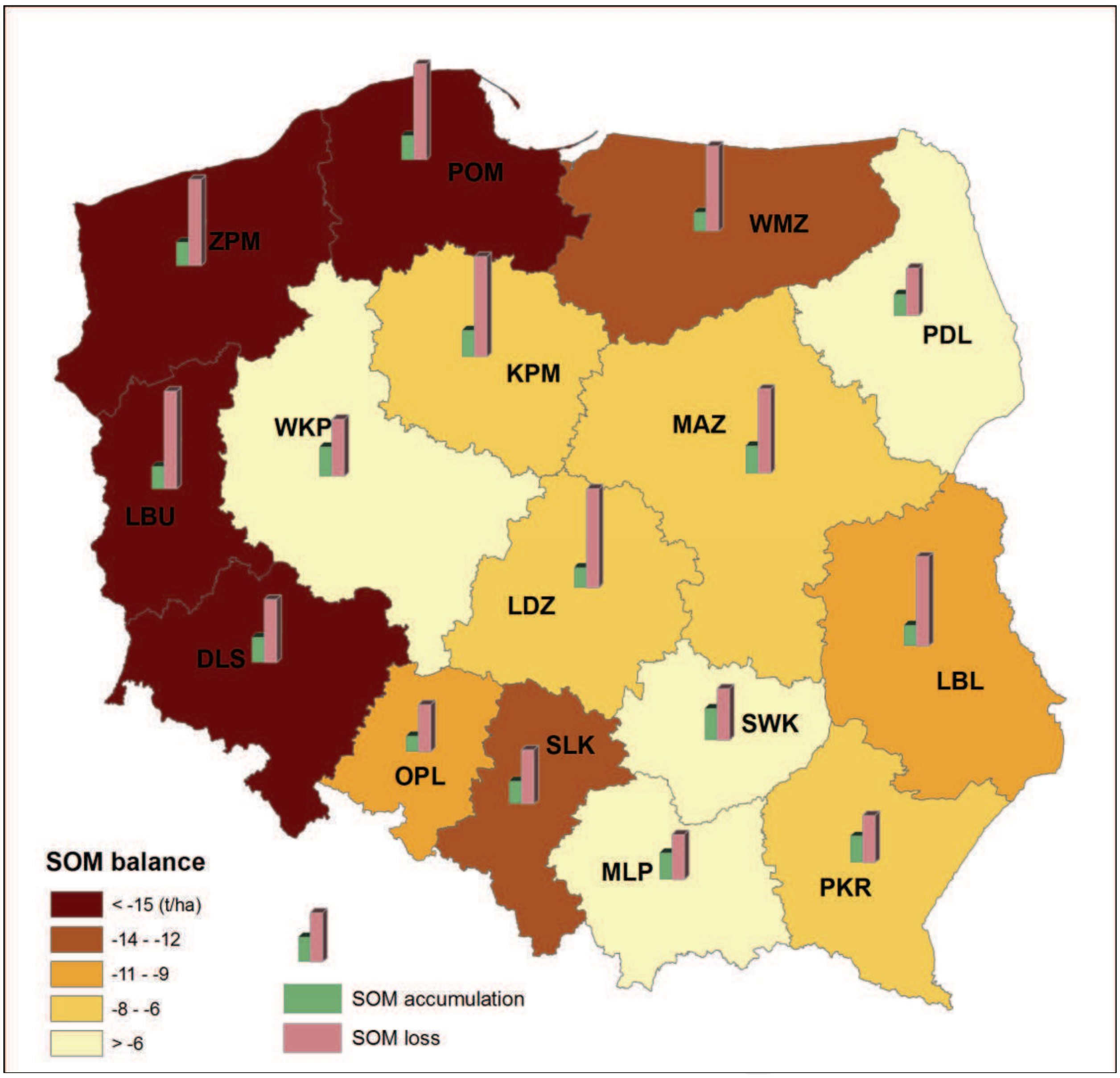

Fig. 1. Forecast loss of soil organic matter (SOM) from agricultural land[1].
Source: own work based on Stuczynski et al., (2007)

[1] Map code: Dolnośląskie (DLS), Kujawsko-pomorskie (KPM), Lubelskie (LBL), Lubuskie (LBU), Lodzkie (LDZ), Małopolskie (MLP), Mazowieckie (MAZ), Opolskie (OPL), Podkarpackie (PKR), Podlaskie (PDL), Pomorskie (POM), Slaskie (SLK), Swietokrzyskie (SWK), Warminsko-mazurskie (WMZ), Wielkopolskie (WKP), Zachodniopomorskie (ZPM)

The second group includes plants with a potential in degrading the soil organic matter. This group includes mainly root crops, root vegetables and corn. The characteristics for this group of crops is very little crop residue, seeded in wide rows, intercrops, heavy maintenance, and the short canopy (cover spacing) increases the distribution of humus resulting in increased erosion. The soil degradation rate for this group of plants ranges from -0.12 to -1.54, and is dependent on the type of soil they are grown on (Fotyma & Mercik, 1992). The mineralisation for these types of plants per year is about 1.0-1.5 t/ha of humus. To compensate for this loss about 15-16 t/ha manure should be used.

The third group include plants with a small negative or neutral impact on soil organic matter. This group of plants includes cereals and oilseeds. Cereals previously were treated as plants degrading the soil organic matter, but changes in agricultural techniques (density of straw, shortening of straw), and combine harvester collection, leaves a lot of crop residue that significantly reduces their negative impact on the balance of soil organic matter. It should be emphasized that the quality of cereal crop residues is worse due to the unfavourable ratio of carbon to nitrogen. The soil degradation rate for this group of plants ranging from -0.49 to -0.56, is dependent on the type of soil they are grown on (Fotyma & Mercik, 1992).

The coefficients values determine the amount of soil organic matter t/ha can enriched or depleted by following a one-year cultivation of the plants or through the application of 1t/ha dry matter of different natural and organic fertilizers. Using these coefficients can be simplified way to determine the soil organic matter balance for a farm, region or country. A positive result indicates a normal economy and organic matter, thus ensuring the long-term stabilisation of humus content at an optimum level. If the balance is negative then changes are necessary. This can be achieved by changing the crop structure (introduction of plants with positive coefficient), or increasing the dosage of organic fertilizers (ploughed straw) or intercrops cultivation for ploughing. Throughout the calculations the following formula was used (see Equation 1):

$$\text{Degradation coefficient} = \frac{\sum(\%\ \text{cereals area x} - 0.53) + (\%\ \text{root crops} \times -1.40) + (...)}{\text{sown area (\%)}} \qquad (1)$$

The numerator is the sum of the ratio (the share of particular groups or species of plants in the crop structure multiplied by the coefficients for these species), while the denominator is the percentage of a sown area (where taking into account all the sown land as 100%). Based on those coefficients following the agricultural use of arable land, allows us to calculate the decreases in the soil organic matter amount by 0.39 to 0.66 t/ha for particular voivodeships and approximately 0.53 tonnes per one ha per year in Poland (Kus et al., 2006). Figure 2 presents carto-diagram which shows spatial differentiation, presented by standard deviation methods.

The best situation of soil organic matter was calculated for the voivodeships of Warminsko-mazurskie, Podlaskie followed by the Malopolskie, and their positive situation is associated with a high share of legumes or their mixtures with grasses. An adverse situation appears in the Dolnoslaskie and Opolskie voivodeships, where there is a large share of root crops and maize. To offset this loss, approximately six tons of manure should be applied on every hectare of arable land used. The calculations (Kus et al., 2006) show that the national average production of natural fertilizers (manure) was approximately 7.3 t/ha of sowing area (Fig. 3).

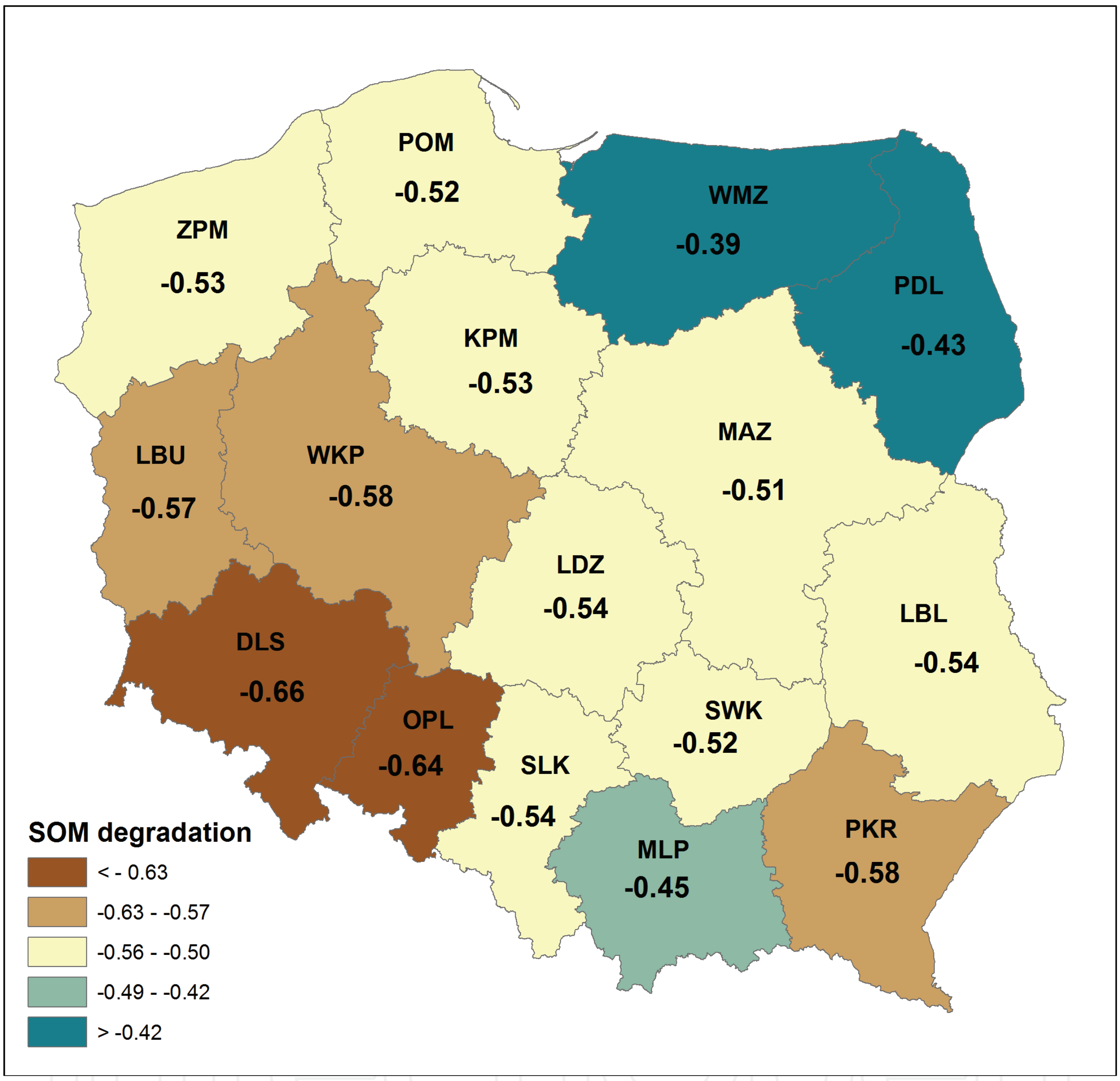

Fig. 2. The coefficient values of soil organic matter degradation for the individual regions calculated for the cropping system average for 2002-2005[1].
Source: own work based on Kus et al., (2006)

The highest amount of manure was produced in the Podlaskie voivodeship due to high livestock and low sowing area. This led to a significant surplus of soil organic matter in the Podlaskie voivodeship. The lowest production of manure was in the Dolnosląskie and Zachodniopomorskie voivodeships where the sowing area is high and livestock low.
In some voivodeships with a negative value of SOM, a balance can be best achieved through ploughing the straw. Particularly large quantities of straw can be ploughed in four voivodeships, (0.9 - 1.0 t/ha in Opolskie and Lubuskie, about 1.2 t/ha in Zachodniopomorskie and to 1.9 t/ha Dolnoslaskie (Fig. 4). However, in some voivodeships

such as Lubelskie, only 0.2 tons of the straw per 1 ha of arable land can be ploughed. In total, across the country three million tonnes of straw, which is less than 12% of the collected straw, could be allocated for ploughing.

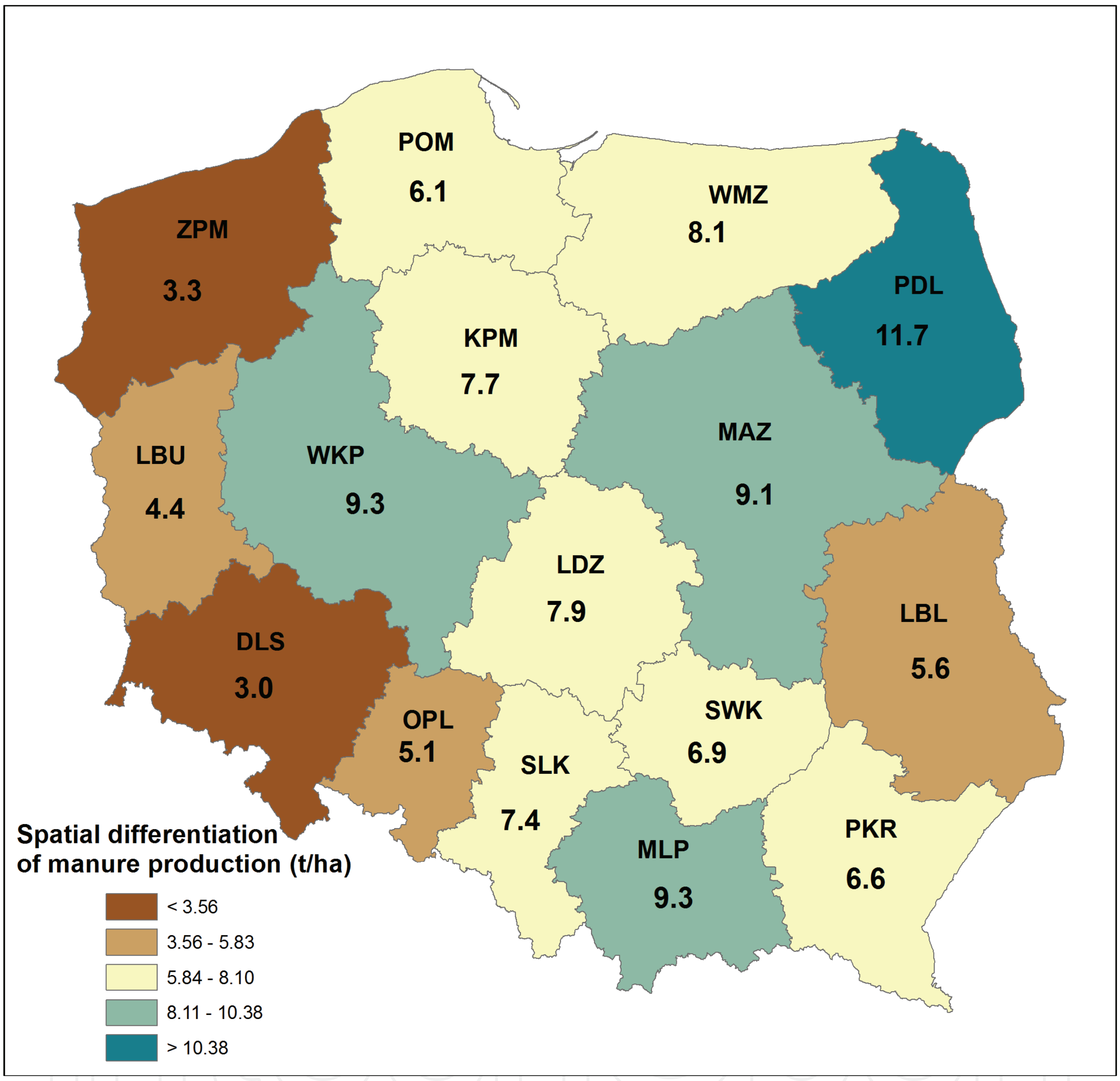

Fig. 3. The production of manure per 1 ha of sowing area (average 2002-2005)[1].
Source: own work based on Kus et al., (2006)

2.3 Assessment of C organic balances

As indicators for determining a positive, neutral or negative balance of carbon in the soil the scale developed by Korschens et al., (2004) can be used - presented in the table 1. The presented scale has a range between below -200 kg/ha/y and values above 300 kg/ha/y. Comparing the results with this scale allows judging the impact on soil functions and potential yield performance of plants. It is important to emphasize that the carbon balance of more than 300 increases high emissions of nitrogen. Therefore, soil carbon sequestration cannot be considered in isolation from the nitrogen emissions.

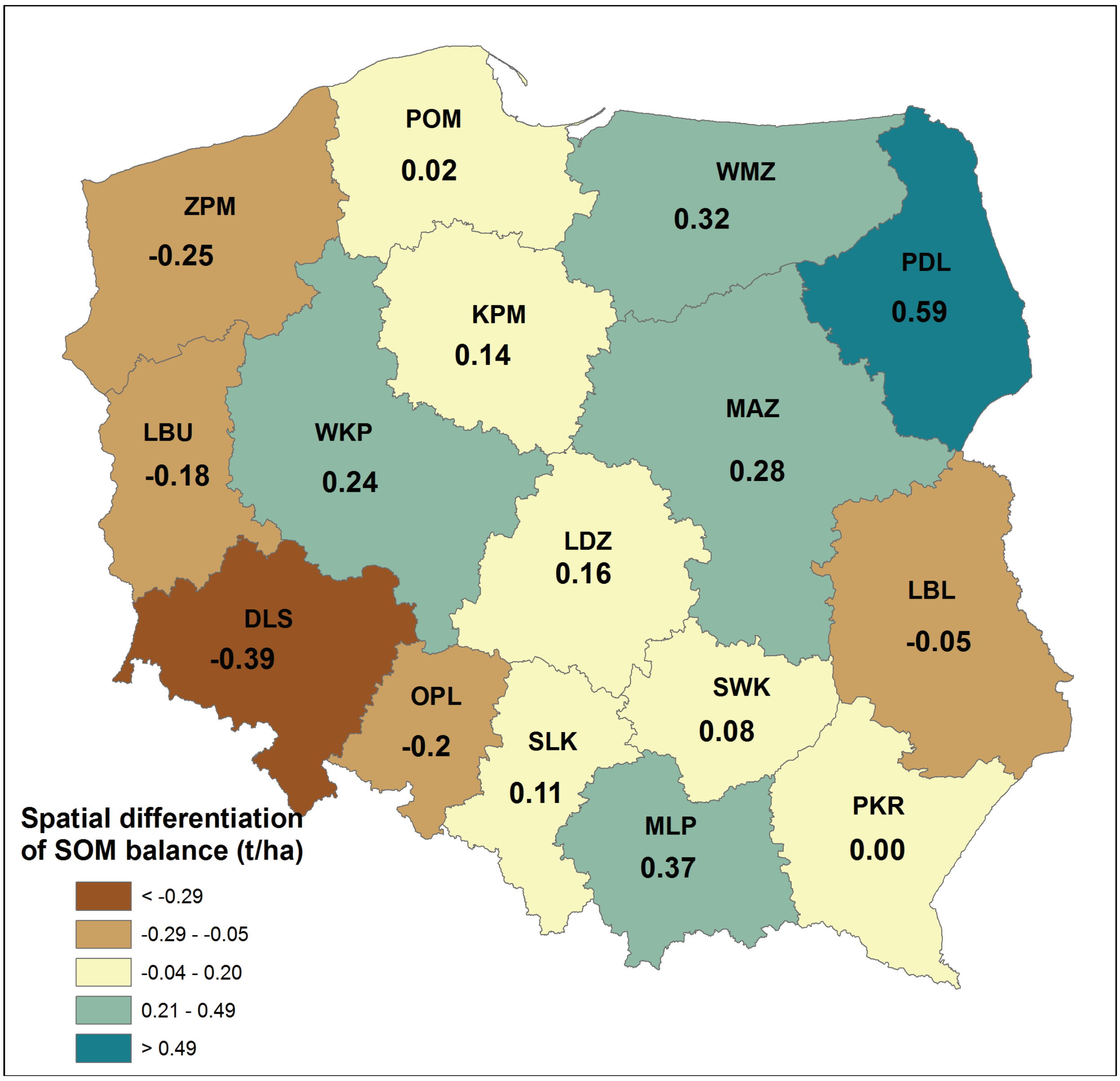

Fig. 4. Balance of soil organic matter (t/ha) in voivodeship[1].
Source: own work based on Kus et al., (2006)

Balance		Impact
kg C/ha/y	group	
<-200	very low	unfavourable influence of soil functions and yield performance
-200- -75	low	medium-term tolerable, especially on soils enriched with humus
-75- +100	optimal	optimal in terms of yield loss at low risk of long-term site-adapted setting humus content
100-+300	high	medium-term tolerable, especially on impoverished soils with humus
>300	Very high	increased risk of nitrogen loss, low efficiency

Table 1. Evaluation of the carbon organic balance (VDLUFA, 2004)

2.4 The potential land use change for sequestering carbon in soils

Land use change significantly affects soil carbon stock (Guo & Gifford, 2002). Most long-term research shows significant changes in SOC (Smith, 2008). Land use change can play a positive or negative role in mitigating global warming by sequestering carbon from the atmosphere into vegetation and soils. Many land use activities generate carbon sequestration and thus counteract the impact of emissions made in a different place. There are two components of estimated emissions from land use change: decomposition of vegetation and mineralisation/oxidation of humus or SOC (Lal, 2004b). The conversion of arable land to woodland may result in a substantial increase in soil carbon sequestration from 0.3 to 0.6 t C/ha/y. The conversion of arable land to grassland may result in a substantial increase in soil C sequestration from 1.2 to 1.7 t C/ha/y. The potential carbon sequestration rate in the conversion of woodland to arable land was -0.6 t C/ha/y, while the conversion of grassland to arable land was at a rate of between -1.0 and -1.7 t C/ha/y (Freibauer et al., 2004). In addition, Guo & Gifford (2002) in a long-term experiment had shown that a conversion of forestland or grassland to arable land caused a significant loss of SOC, whereas a conversion of forestry to grassland did not result in a loss for all cases. The largest potential decrease of SOC loss is in land use change on highly organic soil (Gronlund et al., 2008). Drainage and cultivation of peat soils stimulates soil organic matter (SOM) mineralisation, which substantially increases CO_2 emissions from soils. Because of this, the Directive 2009/28/EC prohibits the use of land with high carbon stock (i.e. wetlands, continuously forested areas, and peat land) for the production of biofuels.

2.5 Potential of management change for sequestering carbon in soils

Correct agricultural practices of the soil can have a significant influence for carbon sequestration. A change in conventional cultivation practises has an important role in improving the soil's structure. Implementing modern practises like reduced tillage, no tillage or conservation tillage can significantly improve the soil's organic matter. Conventional tillage is defined as the mechanical manipulation (ploughing, disking and harrowing) of the top soil that leaves no more than 15% of the ground cover with crop residues. Such tillaging tends to disrupt the soil structure, accelerating the decomposition of soil organic matter, and making the bared topsoil vulnerable to erosion by rain and wind (Hillel & Rosenzweig, 2009). The alternative for conventional tillage is conservation tillage. The European Conservation Agriculture Federation (ECAF) defines conservation tillage as soil management practices, which minimise the disruption of the soil's structure, composition and natural biodiversity, thereby also minimising erosion and degradation, and water contamination (ECAF, 2002). By avoiding deep ploughing, this can increase the sequestration rate by 1.4 to 4.1 t C/ha/y. There is a growing interest in the impact of conservation tillage practices on carbon sequestration in recent years. According to Holland (2004), agriculture can act both as a sink and a source of CO2 emission and the use of conservation practices by agriculture could decrease this emission. The coverage of the soil surface with straw and cover crops, increases biomass productivity and turns the soil into a tremendous carbon sink. Reducing the intensity of soil cultivation lowers energy consumption and the emission of carbon dioxide, while carbon sequestration is raised through the increase of soil organic matter (Holland, 2002). On the basis of long-term experiments, West & Post (2002) concluded that conversion of conventional tillage to no-till sequesters an average of 0.57±0.14 t C/ha/y. Long-term field experiments are the most reliable source information about GHG emissions from different agricultural systems. However, they are difficult to manage and limited by time and costs (Li et al., 2009). Reduced tillage, enhanced crop residue incorporation, and farmyard manure application each increased soil C-sequestration, increased N2O emissions, and had little effect on CH4 uptake. Over 20 years, increases in N2O emissions, which were converted into CO2-equivalent emissions with 100-year global warming potential multipliers, offset 75–310% of the carbon sequestered, depending on the scenario (Li et al., 2005). Simulation models provide an alternative method of assessment of agricultural practices effects (Farge et al., 2007). Many models have been developed to describe the responses of crop growth, soil water dynamics and soil biogeochemistry such as Roth C (Groenigen et al., 2010) for organic carbon turnover, CENTURY (Grant et al., 2004) or DNDC (Li et al., 1992; Giltrap et al., 2010) for carbon and nitrogen cycles. In order to calculate the management influence of carbon changes, we used ‘Tool for Estimation of Changes in Soil Carbon Stocks associated with management Changes in Croplands and Grazing Lands based on IPCC Default Data’. At the moment Poland is assumed as having a cold temperate climate with both maritime and continental elements impact. The conversion from full tillage to reduced tillage under cold a temperate climate with maritime influence can cause the annual carbon stock to change by approximately 0.56 t C/ha, while the conversion from full tillage to no tillage 0.76 t C/ha depending on type of climate, soil, and the amount of fertiliser applied while under a cold temperate climate with a continental influence is 0.20 and 0.28 t C/ha respectively.

3. Potential of cultivation energy plants for sequestering carbon in soils

The soil carbon in croplands can be increased by planting more forages, and increasing residue inputs from plants with a high biomass potential. Hopes for increased soil carbon sequestration are associated with an increase in large-scale energetic crops cultivation. Energy crops are characterised by rapid growth and large amount of biomass produced and consequently a very large amount of crop residue left at the field. Annually about 30% of the senescent leaves and post harvest remnants are entering the soil (Matthews & Grogan 2001). One factor that is highly important for the amount of carbon sequestration in soil is that these perennial plants are grown for about 20 years on one field. The cultivation of energy crops is associated with greenhouse gas emissions (burning fuel, the production of fertilizers, crop protection). The assumption is that carbon sequestration of around 0.25 t C/ha/y resulting from energetic crops cultivation, allows biomass combustion to be neutral in terms of greenhouse gas emissions (Volk et al., 2004). Nevertheless, different authors found that the carbon sequestration rates for these cultivars are different. Bradley and King (2004), determined the carbon sequestration in forests and willows cultivations at 0.15-0.22 t C/ha/y, whereas in Miscanthus cultivation it was at 0.13-0.20 t C/ha/y. According to Matthews and Grogan (2001), carbon sequestration in the surface layer of the soil (0-23 cm) was at 0.31 for forests, and 0.41 for the cultivation of willow, whereas for Miscanthus it was measured at 0.93 t C/ha/y. Freibauer et al., (2004) and Smith (2004), determined the carbon sequestration in cultivations of energy crops at appropriately 0.60 and 0.62 t C/ha/y. Unfortunately for the carbon sequestration the liquidation of biocrops plantations causes large losses of accumulated carbon. This topic is not yet completely understood and requires further work from researchers.

3.1 Materials and methods

As mentioned before Poland has a temperate climate on the Western side of the Vistula River with larger influence of maritime climate than on the Eastern side of the river that has a larger influence of continental climate. For research on soil carbon sequestration dependant on the climate, we have divided Poland along the Vistula River into two regions of climatic influence. We have selected randomly ten experimental positions with available climate data from the MARS Database elaborated by the Joint Research Centre European Commission – 5 grids cells (50 km x 50 km) in each region.
For a simulation of total inflows of carbon into soil under willow and Miscanthus crops in a 19 year period, the DNDC model was used. The model was calibrated based on the data from experimental fields established in 2003 at two Experimental Stations of the Institute of Soil Science and Plant Cultivation, Puławy. The experimental fields are located in the Experimental Station Pulawy-Osiny on heavy black earth, and at the Experimental Station in Grabow on medium-heavy soil where five genotypes of Miscanthus and four clones of willow were planted.

3.2 Results and discussion

The results have shown that the significant difference in yield of Miscanthus grown under two different climate influences, as well as organic matter input, while soil organic matter did not denote a statistically significant difference. In comparing the case of willow, the yield was not significantly different, but the input of organic matter and soil organic matter was significantly different. This might be explained as the temperature had an impact in the case of Miscanthus but it did not influence willow plants. The opposite situation was found in the effect of precipitation. Borzęcka-Walker et al., (2008), did not find any significant differences between the yields of willow clones. The yield of willow grown in two different localisations, ranged from 11.1 - 13.7 t/ha/y. There were lower simulated yields for willow cultivations (13.8-18.1 t/ha/y) located on very good soils of Eastern Europe (Fischer et al., 2005). It can be assumed that the limited water influenced the experimental yield of willow. The dry matter yield of Miscanthus genotypes was significantly different within an average of 10.2 - 20.7 t/ha/y at both localisations. The yield for the first year of the experiment was low; this could be because it was the second year of cultivation when the plants are still not mature enough to obtain an economic yield (Clifton-Brown & Lewandowski 2000). In the second year of the experiment, the yield witnessed a high increase. In the third year of experiment this was characterised with very bad weather conditions, including a late spring ground-frost and long summer draught. The yields were approaching the presupposed simulated yields for Miscanthus cultivations (17.7-21.8 t/ha/y) located on very good soils of Eastern Europe (Fischer et al., 2005). It can be assumed with a high probability that the limited water in 2005 did not influence the experimental Miscanthus yield, but there was an influence from weather condition in 2006 (Borzecka-Walker et al., 2008).

	Miscanthus		Willow	
	maritime	continental	Maritime	continental
yield t C/ha/y	4.8	5.1	4.8	5.0
organic matter input t C/ha/y	5.4	6.1	2.9	3.5
soil organic carbon t C/ha/y	1.5	1.7	0.71	0.85

Table 2. Soil carbon (C) balance (t C ha y) under Miscanthus and Willow cultivation

The aboveground biomass has a high influence on the amount of carbon sequestration, which enters the soil usually in the form of senescent leaf mass and postharvest remnants. Kahle (2001) measured in Germany that about 3.0-7.5 t/ha/y aboveground biomass full to soil. Matthews and Grogan (2001) in Great Britain estimated the inflow of the organic matter at a level of 7.5 t/ha/y, while for Poland it was calculated at from 2.63 to 6.58 t/ha/y (Borzecka-Walker et al., 2008). The organic matter input table 2 shows a greater potential for carbon mitigation for Miscanthus than for willow. Despite the very different movement of C into the soil plantations of willow and Miscanthus, most of this element accumulates in the litter. This is labile to C fraction, which in total will be mineralised and released as CO_2 in a short time after the restoration of conventional land use. Moderately stable fractions of carbon in the form of living organisms (humads) is the second largest fraction of sequestrated carbon. In almost all cases it will be transformed into humus after a change of use in the plantation. The stable fraction C (humus) in the lifetime of the plantation rose to a negligible extent. So it can be concluded that an effective carbon sequestration expressed the sum of humus fractions and humads. For willow and Miscanthus (tab. 3), during the period of cultivation it was respectively at 0.20, 0.21 for the maritime climate and the 0.23 and 0.25 in the continental climate. The obtained values from the model are close to the obtained values by Bradley & King (2004), who have determined the carbon sequestration in forests and willows cultivations at 0.15-0.22 t C/ha/y, whereas in Miscanthus cultivations they were at 0.13-0.20 t C/ha/y. According to Matthews & Grogan (2001), carbon sequestration in the surface layer of the soil (0-23 cm) was at 0.31 for forests, and 0.41 for the cultivation of willow, whereas for Miscanthus it was measured at 0.93 t C/ha/y. The net soil carbon sequestration in Miscanthus crops was around 0.38-0.95 t C/ha/y and 0.22-0.39 t C/ha/y for coppice willow (Borzecka-Walker et al., 2008). Freibauer et al., (2004) and Smith (2004) have determined the carbon sequestration in cultivations of energy crops appropriately at 0.60 and 0.62 t C/ha/y. Much of the carbon mitigation potential associated with the use of SRC willow and Miscanthus as bioenergy crops arises from their indefinite capacities as 'carbon neutral' alternatives to fossil fuel combustion (Grogan & Matthews, 2001). The assumption is that carbon sequestration of around 0.25 t C/ha/y resulting from energy crops cultivation makes biomass combustion neutral in terms of greenhouse gas emissions (Volk et al., 2004). The new cultivations will result in changes in fossil-fuel use, agricultural inputs, and carbon emissions with fossil fuels and other inputs. Management practices that alter crop yields and land productivity can affect the amount of land use crop production with further significant implications for both emissions and sequestration potential (West & Marlnd, 2003; Schneider & Mccarl, 2003).

SOM	Litter	Humads	Humus
Maritime			
Willow	0.28	0.19	0.01
Miscanthus	0.86	0.20	0.01
Continental			
Willow	0.32	0.21	0.02
Miscanthus	0.91	0.22	0.03

Table 3. Soil organic matter (SOM) pools under Miscanthus and willow cultivation

The organic matter input (tab. 2) is basically consisting of litter and dead roots fractions. Miscanthus harvested in autumn delivers approximately 20% of leaf mass and some of underground biomass while 30 % of leaf mass and some underground biomass from spring harvest is entering the soil. In compare 100 % of willow leaf mass and some of underground biomass is entering the soil. Soil organic matter includes tree pools: very labile fraction of litter, labile humads, and passive humus (tab.3).

4. Conclusion

Agriculture practices have an important role to play in mitigating climate change due to atmospheric enrichment of CO_2 and other greenhouse gases. To improve the negative balance of soil carbon sequestration in Poland, corrective action should be taken. Land management can strongly influence soil carbon stocks and careful management can be used to increase soil carbon sequestration. It is important to propose contemporary management practises to farming like the conversion from tillage to no tillage systems, incorporation of cover crops, forages in crop rotation, as well as a liberal use of crop residues and biosolids like mulch. Special care should be taken of integrated nutrient management including compost/manures and precision use of fertilizers and integrated pest management. A very important role can be played by the implementation of biocrops which are characterised with very high potential of carbon sequestration and much lower GHG emission during the cultivation.

When considering carbon sequestration it should be mandatory to combine these analyses with nitrogen (N) as carbon and nitrogen move through terrestrial ecosystems coupled with biogeochemical cycles, and increasing C stocks in soils and vegetation which have an impact on the N cycle.

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6. References

Borzecka-Walker, M.; Faber, A. & Borek, R. (2008). Evaluation of carbon sequestration in energetic crops (Miscanthus and coppice willow). *Int. Agrophysics*, No 22, 185-190.

Bradley, R.I. & King, J.A. (2004). A review of farm management techniques that have implications for carbon sequestration – validating an indicator. OECD Expert Meet. Farm Management Indicators and the Environment, 8-12 March, Palmerston North, Avaialble from http://webdomino1.oecd.org/comnet/agr/farmind.nsf/22afaebba539ba74c1256a3b004d5175/b3b8d25f219f4ae3c1256bd5004874f1/$FILE/Bradley1.pdf

Clifton-Brown, J.C.; & Lewandowski, I.; (2000). Overwintering problems of newly established Miscanthus plantations can be overcome by identifying genotypes with improved rhizome cold tolerance. *New Phytol.* No 148, 287-294.

COM, (2000) 769: Green Paper: Towards a European strategy for the security of energy supply

Directive, 2003/96/EC. (2003). The European Parliament and of The Council on restructuring the Community framework for the taxation of energy products and electricity.

Directive, 2009/28/EC. (2009). The European Parliament and of The Council on the promotion of the use of energy from renewable sources amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

Dumanski, J.; Desjardins, R.L.; Tarnocal, C.; Monreal, EG.; Gregorich, E.G.; Kirkwood, V. &Campbell, C.A. (1998). Possibilities for future carbon sequestration in Canadian agriculture in relation to land use changes. *Climatic Change,* Vol. 40, 81-103.

ECAF (European Conservation Agriculture Federation). Observations on the Communication form the European Commission: Towards a Thematic Strategy for Soil Protection (COM (2002) 179 final) www.ecraf.org

Farge, P.K.; Ardő, J.; Olsson, L.; Rienzi, E.A. & Pretty, J.N. (2007). The potential for soil carbon sequestration in the three tropical dryland farming systems of Africa and Latin America: a modeling approach. *Soil Tillage Res,* Vol. 94, 457-472.

Fischer, G.; Prieler, S.; & van Velthuizen, H.; (2005). Biomass potentials of Miscanthus, willow and poplar: results and policy implications for Eastern Europe. Northern and Central Asia. *Biomass and Bioenergy*. No 28,119-132.

Fotyma, M. & Mercik, S. (1992). Współczynniki reprodukcji glebowej materii organicznej. In: *Chemiarolna*, PWN Warszawa.

Franzluebbers, A.J. & Follett, R.F. (2005). Greenhouse gas contributions and mitigation potential in agricultural regions of North America: Introduction. *Soil & Tillage Research*, Vol. 83, 1–8.

Freibauer, A.; Rounsevell, M.; Smith, P. & Verhagen A. (2004). Carbon sequestration in European agricultural soils. *Geoderma,* Vol. 122, 1–23.

Giltrap, D.L.; Li, Ch. & Saggar, S. (2010). DNDC: A process-based model of greenhouse gas fluxes from agricultural soils. *Agriculture Ecosystems and Environment,* Vol. 136, 292-300.

Grant, B.; Smith, W.N.; Desjardins, R.; Lemke, R. & Li, C. (2004). Estimated N_20 and CO_2 emissions as influenced by agricultural practices in Canada. *Climatic Change,* Vol. 65, 315-332.

Groenigen, K.J.; Hastings, A.; Forristal, D.; Roth, B.; Jones, M. & Smith, P. (2010). Soil C storage as affected by tillage and straw management: An assessment using field measurements and model predictions. *Agriculture Ecosystems and Environment,* Vol. 140, 218-225.

Grogan, P. & Matthews, R. (2001). Review of the potential for soil carbon sequestration under bioenergy crops in the U.K. Report for U.K. Dept. of Environment, Food, and Rural Affairs. Contract NF 0418.

Gronlund, A.; Hauge, A.; Hovde, A. & Rasse, D.P. (2008). Carbon loss estimates from cultivated peat soils in Norway: a comparison of three methods *Nutr Cycl Agroecosyst,* Vol. 81, 157–167.

Guo, L.B. & Gifford, R. M. (2002). Soil carbon stocks and land use change: a meta analysis. *Global Change Biology,* Vol. 8, 345-360.

Hillel, D. & Rosenzweig, S. (2009). Soil and carbon climate change. *CSA News,* Vol. 54, No 6, 4-11.

Holland, J.M. (2004). The environmental consequence of adopting conservation tillage in Europe: reviewing the evidence. *Agriculture Ecosystems and Environment,* Vol. 103, 1-25.

Hutchinson, J.J.; Campbell, C.A. & Desjardins, R.L. (2007). Some perspectives on carbon sequestration in agriculture. *Agricultural and Forest Meteorology,* Vol. 142, 288–302.
IPCC, (2000). IPCC special report on Impacts. Adaptation and Vulnerability. http://www.grida.no/climate /ipcc_t ar/wg2/index.htm
IPCC, (2007). Fourth Assessment Report. Synthesis Report. http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf
Kahle, P.; Beuch, S.; Boelcke, B.; Leinweber, P.; & Schulten, H.R.; 2001: Cropping of Miscanthus in Central Europe: biomass production and influence on nutrients and soil organic matter. *Eur. J. Agron.* No 15: 171-184.
Knowler, D. & Bradshaw, B. (2007). Farmers' adoption of conservation agriculture: A review and synthesis of recent research. *Food Policy,* Vol. 32, 25-48.
Kus, J.; Madej, A. & Kopinski, J. (2006). Bilans słomy w ujęciu regionalnym. *Studia i Raporty IUNG-PIB,* Wyd. IUNG, Pulawy, No 3, 211-225.
Lal, R. (2004a). Agricultural activities and the global carbon cycle. *Nutrient Cycling in Agroecosystems,* Vol. 70, 103–116.
Lal, R. (2004b). Soil carbon sequestration to mitigate climate change. *Geoderma,* Vol. 123, 1 – 22.
Li, C.; Frolking, S. & Butterbach-Bahl, K. (2005). Carbon sequestration in arable soils is likely to increase nitrous oxide emissions, offsetting reductions in climate radiative forcing. *Climatic Change,* Vol. 72, 321-338.
Li, C.; Frolking, S. & Frolking, T.A. (1992). A model of nitrous-oxide evolution from soil driven by rainfall events: model structure and sensitivity. *Journal of Geophysical Research–Atmospheres,* Vol. 97, 9759–9776.
Li, T.; Feng, Y. & Li, X. (2009). Predicting crop growth under different cropping and fertilizing management practices. *Agricultural and Forest Meteorology,* Vol. 149, 985-998.
Matthews, R.B. & Grogan, P. (2001). Potential C-sequestration rates under short-rotation coppiced willow and Miscanthus biomass crops: a modelling study. *Aspects Appl. Biol.,* Vol. 65, 303-312.
Ringius, L. (2002). Soil carbon sequestration and the CDM: opportunities and challenges for Africa. *Climatic Change,* Vol. 54, 471–495.
Schneider, U.A. & Mccarl, B.A. (2003). Economic potential of biomass based fuels for greenhouse gas emission mitigation. *Environmental and Resource Economics,* Vol. 24, 291–312.
SEC. Commission Staff Working Document. (2009). The role of European agriculture in climate change mitigation. Brussels, 23.7.2009, 1093 final.
Smith, P. (2004). Carbon sequestration in croplands: the potential in Europe and the global context. *Europ. J. Agronomy,* Vol. 20, 229–236.
Smith, P. (2008). Land use change and soil organic carbon dynamics. *Nutr Cycl Agroecosyst,* Vol. 81, 169–178.
Smith, P.; Powlson, D.S.; Glendining, M.J. & Smith, J.U. (1997). Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments. *Global Change Biol,* Vol. 3, 67– 79.
Smith, P.; Powlson, D.S.; Smith, J.U.; Falloon, P.D. & Coleman, K. (2000). Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture. *Global Change Biol,* Vol. 6, 525–539.

Stuczynski, T.; Kozyra, J.; Lopatka, A.; Siebielec, G.; Jadczyszyn, J.; Koza, P.; Doroszewski, A.; Wawer, R. & Nowocien, E. (2007). Przyrodnicze uwarunkowania produkcji rolniczej w Polsce *Studia i Raporty IUNG-PIB,* Wyd. IUNG, Pulawy, No 7, 77-115.

Terelak, H.; Motowicka-Terelak, T.; Wroblewska, E.; Gawrysiak, L. & Pietruch, C. (2001). Mapa zawartości substancji organicznej w glebach użytków rolniczych Polski. Wyd. IUNG, Puławy.

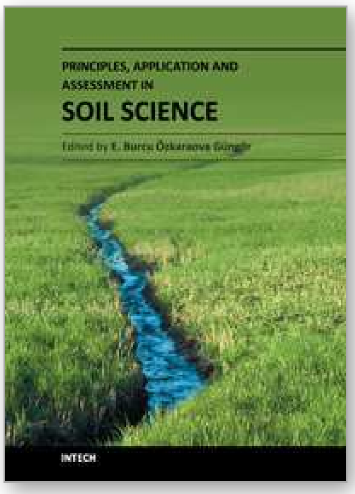
VDLUFA (2004): VDLUFA Standpunkt Humusbilanzierung, Methode zur Beurteilung und Bemessung derHumusversorgung von Ackerland, Bonn 2004, http://www.vdlufa.de, (accessed April 2004).

Vleeshouwers, L.M. & Verhagen, A. (2002). Carbon emission and sequestration by agricultural land use: a model study for Europe. *Global Change Biol,* Vol. 8, 519–530.

Volk, T.A.; Verwijst, T.; Tharakan, P.J.; Abrahamson, L.P. & White, E.H. (2004). Growing fuel: a sustainability assessment of willow biomass crops. *Front Ecol. Environ,* Vol. 2, No 8, 411- 418.

West, T.O. & Marlnd, G. (2003). Net carbon flux from agriculture: Carbon emissions, carbon sequestration, crop yield, and land use change. *Biogeochemistry,* Vol. 63, 73-83.

West, T.O. & Post, W.M. (2002). Soil Organic carbon sequestration rates by tillage and crop rotation: a global analysis. *Soil Science Society of America Journal,* Vol. 66, 1930-1946.



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Our dependence on soil, and our curiosity about it, is leading to the investigation of changes within soil processes. Furthermore, the diversity and dynamics of soil are enabling new discoveries and insights, which help us to understand the variations in soil processes. Consequently, this permits us to take the necessary measures for soil protection, thus promoting soil health. This book aims to provide an up-to-date account of the current state of knowledge in recent practices and assessments in soil science. Moreover, it presents a comprehensive evaluation of the effect of residue/waste application on soil properties and, further, on the mechanism of plant adaptation and plant growth. Interesting examples of simulation using various models dealing with carbon sequestration, ecosystem respiration, and soil landscape, etc. are demonstrated. The book also includes chapters on the analysis of areal data and geostatistics using different assessment methods. More recent developments in analytical techniques used to obtain answers to the various physical mechanisms, chemical, and biological processes in soil are also present.