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Assessment of existing soil organic carbon stocks and changes at a national and regional level in Poland

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Abstract

The paper presents the usefulness of IPCC Tier 1 methodology for the calculation of annual carbon stock changes for Annex V of the Directive: The promotion of the use energy from renewable sources (RED, 2009/28/EC). The presented results showed that carbon stocks should be calculated for a cold temperate dry climate, which is typical for Poland. In the research we did not find sufficient reasons to perform such calculations for a cold moist temperate climate region, which is also distinguished by the IPCC in Poland. The existing carbon stocks in cultivated high clay activity mineral, sandy and spodic soils were not statistically significantly different, but were more than often lower regarding the IPCC standards for carbon stock values. Spatial differentiations of annual carbon stock changes were low for three of the long-term studied cultivated soils under reduced tillage and no tillage systems with medium, high, or no manure input. Subsequently, the average values of annual carbon stock changes for all of Poland could be accepted and taken into account as binding magnitudes of organic carbon sequestrations for the estimation of greenhouse gas (GHG) emissions in the life cycle of liquid biofuels. However, calculations should be done for the NUTS-2 regions, if farms apply these systems of cultivation with a high OM input of manure.

Key words: Organic carbon, stocks, agricultural management improvement, Directive 2009/28/EC.

Introduction

The soil organic carbon (SOC) determines important functions of agro-ecosystems' that influence soil fertility, water-holding capacity, soil structure and many other functions [3, 4]. As well as these functions it also has a global importance, because a carbon cycle can affect the atmospheric levels of greenhouse gases (GHG) [6]. These have many consequences, but here the existing carbon stocks and changes in the managed agricultural mineral soils are regarded as connected to the mandatory saving of GHG emissions as required by the Directive: The promotion of the use of energy from renewable sources [2]. Many scientific reports have highlighted a significant impact of land management on the enlargement SOC stocks [1]. According to RED, there is a possibility to subtract annualised SOC stock changes from GHG emission in the life cycle of biofuels if agricultural management is improved. The calculation of SOC stocks should be completed, based on the methodology developed by the Intergovernmental Panel on Climate Change (IPCC), and presented in the Guidelines for National Greenhouse Gas Inventories [1, 5]. For the calculation of the annualised carbon stock changes in soil, climate, soil type, land cover, land management and organic matter (OM) input should be all taken into account. The results of these calculations depend on the form of standard soil carbon stock values in soils, which were established for different climate regions and soil types as standard SOC values in the 0-30 cm topsoil layer (SOC_{ST})[1]. However, it should be remembered that SOC_{ST} values are only provided for mineral soils under native vegetation. There is a need to use existing SOC stocks for agricultural soils for proper estimations of soil carbon accumulation as a result of improved agricultural management. The aim of this study was to estimate the existing SOC stocks in agricultural soils and annual SOC changes under different agricultural management systems at a national and regional level in Poland. In our research, calculations of annual SOC changes were done for reduced tillage and no tillage systems for different residue incorporations of medium or high levels with or without manure.

Materials and Methods

The classification for Poland with cold moist temperate and cold dry temperate climates were checked through the comparison of the long-term climatic water balance maps (precipitation minus evapotranspiration) according to JRC [7] and own research. Existing SOC stocks for soil types, classified according to the Word Reference Base for Soil Resources (WRB) typology were taken from the national database containing 50,000 analyses of organic carbon in topsoil layers (0-30 cm) under agricultural use. The data was averaged to all NUTS-2 regions in Poland for the most common soil types. Because SOC stocks had normal distributions, an analysis of variance was performed in order to evaluate the differences in SOC for two climate regions in Poland, cold dry temperate and cold moist temperate climates. Next, for all the NUTS-2 regions, the annualised carbon stock changes were estimated using standard factors for cropland; land use (F_{LU}), management (F_{MG}) and input (F_I) taken from the recommended methods [1]. The calculations were performed using the official IPCC calculator [5].

The improved agricultural management in this estimation relied on the implementation of reduced and no tillage systems with high or medium manure inputs of OM compared to the conventional tillage system with a medium input of OM. The last one was requested according to cross-compliance of farms without animal production in Poland. Then, the obtained results of annualised carbon stock increases are valid for those farms, which are main producers of raw materials for liquid biofuel production in Poland.

Results and Discussion

In IPCC methodology, a climate region with a cold dry temperate was characterised by a mean temperature of 0 - 10°C and annual precipitation less than evapotranspiration, while the climate with cold moist temperature was characterised by the same temperature range and annual precipitation greater than or equal to evapotranspiration [5]. In compliance with these definitions both climatic regions are distinguished in Poland (Fig. 1).

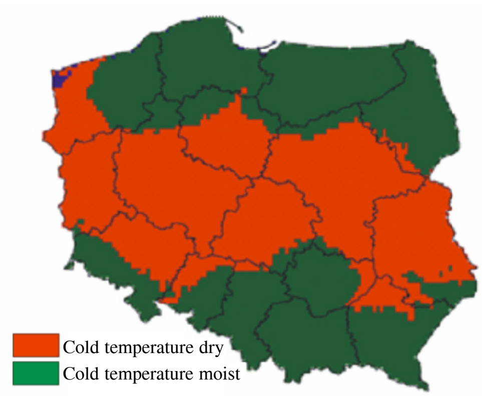

Figure 1. Climate regions in Poland according to IPCC classification modified by JRC [7 †].

According to the latest data of the climatic water balance (precipitation - evapotranspiration), Poland was very close to its climate classification by JRC [7] (Fig. 2). A comparison of Fig. 1 and 2 shows that the climate classification is correct. However, a positive balance was close to zero for a cold temperature of a moist climate.

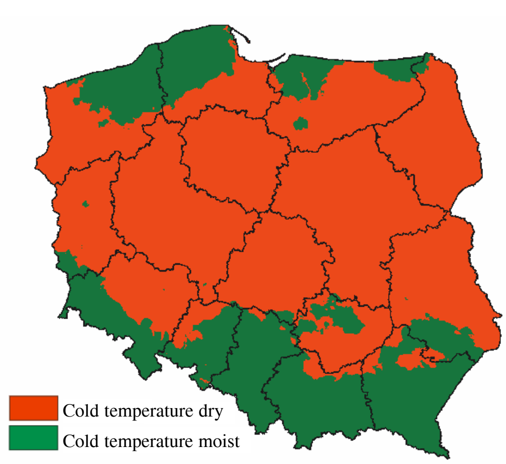

Figure 2. Long- term climatic water balance for Poland.

†In interpreting the data, consideration should be given to the fact that the default values are only provided for mineral soils, under native vegetation and for the topsoil layer of 0-30 cm. In order to better evaluate the default values with actual conditions, a layer of SOC densities for the same characteristics was calculated from HWSD data. The difference between the HWSD map of topsoil stock densities and the IPCC map of default reference values are presented in Fig. 9.

Therefore, it can be expected that existing SOC stocks for Poland should be representative more for the region of a cold dry temperate climate. These results confirm this (Table 1). Calculated values of existing SOC stocks were more close to SOC_{ST} for cold dry temperate climate than for cold moist temperate climate (Table 2).

Table 1. Existing organic carbon stocks (SOC) for main soil types in Poland (Mg C ha^{-1}).

Soil type	Climate regions cold temperate		Significance of difference
	dry	moist	
High clay activity mineral	40	42	ns
Sandy	40	44	ns
Spodic	36	39	ns

ns not significant for P = 0.05.

Table 2. Standard soil organic carbon stocks (SOC_{ST}) according to IPCC values (Mg C ha^{-1})[5].

Soil type	Climate regions cold temperate	
	dry	moist
High clay activity mineral	50	95
Sandy	34	71
Spodic	-	115

In order to confirm assumptions, an analysis of variance was performed in classifying NUTS-2 to both climatic zones identified by the IPCC. The results of an analysis confirmed that the average existing SOC for Poland in both zones do not statistically significantly differ in both climates (Table 1). However, this was more important that SOCs for soil types also are not statistically different. Therefore, it is a sufficient base to perform further estimations of annual SOC changes only for the cold dry temperature climate. The differentiation of average annual SOC stocks changes within NUTS-2 with respect to IPPC values were low for OM inputs of medium and high without manure in reduced and no tillage systems for the studied types of soil (Tables 3-5). However, average differences for high OM input with manure in both tillage practices are higher. The greater differences of annual SOC changes are between reduced and no tillage practices.

Average values of SOC change in Poland for high clay activity mineral soils with medium OM input for reduced tillage were 0.04 and 0.17 Mg C ha^{-1}yr^{-1} for no tillage system (Table 3). In Poland, the application of a high OM input with manure changed by 0.60 Mg C ha^{-1}yr^{-1} in SOC stock, is equal in reduced and in no tillage systems as compared to high OM input without manure. According to IPPC, the difference in SOC changes was 0.68 and 0.73 Mg C ha^{-1}yr^{-1}, respectively, for tillage and no tillage practices.

The average differences of SOC stock change for sandy soil in Poland for medium input of OM were 0.04 and 0.17 Mg C ha^{-1}yr^{-1}, respectively, for tillage and no tillage systems (Table 4). The application of a high OM input with manure increased by 0.57 Mg C ha^{-1}yr^{-1} SOC stock in reduced tillage, while for no tillage by 0.65 Mg C ha^{-1}yr^{-1} with respect to high OM input without manure. According to IPCC, the differences in the SOC stock change were 0.45 and 0.49 Mg C ha^{-1}yr^{-1}, respectively, for tillage and no tillage practices.

The annual SOC changes for spodic soils in Poland for a medium input of OM were at a similar level like for other types of soils (Table 5). In Poland, an application of high OM input with manure changed by 0.54 Mg C ha^{-1}yr^{-1} SOC stock similarly in reduced and in no tillage systems compared to a high OM input without manure.

Table 3. Annual organic carbon stock changes for high clay activity mineral soils in cold temperate climate regions in Poland (Mg C ha^{-1}).

Province (NUTS-2 regions)	Codes	Reduced Tillage			No Tillage		
		Organic matter inputs			Organic matter inputs		
		Medium	High without manure	High with manure	Medium	High without manure	High with manure
Dolnośląskie	PL51	0.04	0.12	0.78	0.20	0.28	1.00
Kujawsko-pomorskie	PL61	0.03	0.09	0.57	0.15	0.21	0.73
Lubelskie	PL31	0.03	0.10	0.62	0.16	0.23	0.79
Lubuskie	PL43	0.03	0.10	0.62	0.16	0.23	0.79
Łódzkie	PL11	0.03	0.09	0.64	0.16	0.23	0.81
Małopolskie	PL21	0.04	0.10	1.37	0.17	0.24	0.83
Mazowieckie	PL12	0.03	0.09	0.59	0.15	0.22	0.75
Opolskie	PL52	0.04	0.11	0.72	0.18	0.26	0.92
Podkarpackie	PL32	0.04	0.11	0.72	0.18	0.26	0.92
Podlaskie	PL34	0.03	0.09	0.59	0.15	0.22	0.75
Pomorskie	PL63	0.04	0.12	0.77	0.19	0.28	0.98
Śląskie	PL22	0.04	0.11	0.73	0.19	0.27	0.94
Świętokrzyskie	PL33	0.03	0.09	0.57	0.15	0.21	0.73
Warmińsko-mazurskie	PL62	0.04	0.10	0.65	0.17	0.24	0.83
Wielkopolskie	PL41	0.03	0.09	0.59	0.15	0.22	0.75
Zachodniopomorskie	PL42	0.03	0.10	0.67	0.17	0.24	0.85
Average		0.03	0.10	0.70	0.17	0.24	0.84
IPCC		0.04	0.12	0.80	0.20	0.29	1.02

Table 4. Annual organic carbon stock changes for sandy soils in cold temperate climate region in Poland (Mg C ha^{-1}).

NUTS-2	Codes	Reduced Tillage			No Tillage		
		Organic matter inputs			Organic matter inputs		
		Medium	High without manure	High with manure	Medium	High without manure	High with manure
Dolnośląskie	PL51	0.04	0.12	0.75	0.19	0.27	0.96
Kujawsko-pomorskie	PL61	0.03	0.09	0.56	0.13	0.19	0.65
Lubelskie	PL31	0.03	0.10	0.62	0.16	0.23	0.79
Lubuskie	PL43	0.04	0.10	0.65	0.17	0.24	0.83
Łódzkie	PL11	0.04	0.11	0.69	0.17	0.25	0.87
Małopolskie	PL21	0.03	0.09	0.59	0.15	0.22	1.37
Mazowieckie	PL12	0.03	0.09	0.57	0.15	0.21	0.73
Opolskie	PL52	0.04	0.13	0.81	0.21	0.30	1.04
Podkarpackie	PL32	0.03	0.09	0.61	0.15	0.22	0.77
Podlaskie	PL34	0.04	0.12	0.75	0.19	0.27	0.96
Pomorskie	PL63	0.04	0.12	0.80	0.16	0.25	0.98
Śląskie	PL22	0.04	0.11	0.73	0.20	0.29	1.02
Świętokrzyskie	PL33	0.03	0.08	0.53	0.13	0.19	0.67
Warmińsko-mazurskie	PL62	0.04	0.13	0.84	0.21	0.31	1.08
Wielkopolskie	PL41	0.03	0.09	0.57	0.15	0.21	0.73
Zachodniopomorskie	PL42	0.04	0.11	0.73	0.19	0.27	0.94
Average		0.04	0.11	0.68	0.17	0.25	0.90
IPCC		0.03	0.09	0.54	0.14	0.20	0.69

The obtained results indicate that a manure application has a higher influence on SOC stock changes than a tillage system.

These are the main options for agricultural improvement of farms without animal production in Poland, producing raw materials for liquid biofuel production. Then, without a greater error of average values of annual carbon stock changes for Poland, this could be accepted and taken into account as binding values of organic carbon sequestrations in the estimation of GHG emissions in the life cycle of liquid biofuels.

Conclusions

It was shown that the calculation of agricultural land SOC stocks changes for the purpose of Annex V to Directive 2009/28/EC according to the IPCC Tier 1 methodology should be done in Poland only for the cold dry temperate climate region. The existing SOC stocks in cultivated high clay activity mineral, sandy and spodic soils were not statistically significantly different despite the fact that were lower in comparison to standard SOC values according to IPCC. Spatial differentiations of annual SOC stocks changes were low for three investigated types of long-term cultivated soils under reduced and no tillage practices with medium and high without OM inputs. Therefore, the average values of SOC stock changes for Poland could be accepted and taken into account as binding magnitudes of SOC sequestrations in the estimation of GHG emissions for the life cycle of liquid biofuels. However, if farms apply these systems of cultivation with high OM inputs with manure, calculation should be done for the NUTS-2 regions.

Table 5. Annual organic carbon stock changes for spodic soils in cold temperate climate region in Poland ($Mg\ C\ ha^{-1}$).

NUTS-2	Codes	Reduced Tillage			No Tillage		
		Organic matter inputs			Organic matter inputs		
		Medium	High without manure	High with manure	Medium	High without manure	High with manure
Dolnośląskie	PL51	0.03	0.09	0.64	0.16	0.23	0.81
Kujawsko-pomorskie	PL61	0.03	0.08	0.51	0.13	0.19	0.65
Lubelskie	PL31	0.03	0.09	0.56	0.14	0.20	0.71
Lubuskie	PL43	0.03	0.09	0.59	0.15	0.22	0.75
Łódzkie	PL11	0.03	0.09	0.59	0.15	0.22	0.75
Małopolskie	PL21	0.03	0.09	0.64	0.16	0.23	0.81
Mazowieckie	PL12	0.03	0.09	0.54	0.14	0.20	0.69
Opolskie	PL52	0.04	0.11	0.73	0.19	0.27	0.80
Podkarpackie	PL32	0.03	0.09	0.54	0.14	0.20	0.69
Podlaskie	PL34	0.03	0.08	0.51	0.13	0.19	0.65
Pomorskie	PL63	0.04	0.11	0.72	0.18	0.26	0.92
Śląskie	PL22	0.04	0.11	0.72	0.18	0.26	0.92
Świętokrzyskie	PL33	0.03	0.08	0.50	0.13	0.18	0.63
Warmińsko-mazurskie	PL62	0.03	0.10	0.62	0.16	0.23	0.79
Wielkopolskie	PL41	0.03	0.09	0.59	0.15	0.22	0.75
Zachodniopomorskie	PL42	0.03	0.10	0.67	0.17	0.24	0.85
Average		0.03	0.09	0.60	0.15	0.22	0.76
IPCC		-	-	-	-	-	-

- was not defined.

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