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Modelling the impact of climate change on miscanthus and willow for their potential productivity in Poland

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Abstract
One of the priorities for the Polish policy on anthropogenic global warming mitigation is increasing the area of agricultural crop production dedicated for energy purposes. The crops that are often most considered for this purpose are miscanthus and willow. According to previous research, the area dedicated for these crops could cover up to 1.59 M ha. This area is considerably limited by climatic conditions, water limitation factors and soil suitability. Furthermore in recent years, the frequency of drought conditions has been increasing during the summer, also most scenarios on climate change have predicted more precipitation during the winter as well as less precipitation during the summer. For these reasons, an evaluation into the impact of climate change on the potential productivity of willow and miscanthus using climate change scenarios is essential for decision-making proposes. The aim of this study was to determine the potential yield of miscanthus and willow in Poland for the current climate conditions and for climate change scenarios. For the modelling a DeNitrification-DeComposition (DNDC) model was used. The calculations in the DNDC model were done with a 99-year stochastic weather series characterised by a temporal climate (1971-2000), as well as scenarios describing climate conditions for 2030 and 2050. Simulations were conducted for the most typical soil types, suitable for willow and miscanthus production in Poland. The simulations for climate change scenarios for 2030 and 2050 showed a rather small but significant decrease in the yield level of willow and miscanthus in Poland, and a significant change in the potential C sequestration and reductions in the nitrous oxide emission level.

Key words: Climate change, miscanthus, willow, soil carbon, greenhouse gases, nitrates leaching, DNDC.

Introduction

Primary energy consumption by fuel in the European Union for 2009 was at 9%, whereas in Poland it was at 6.6%. The differences in renewable energy primary production in the European Union and Poland are huge. The composition of renewable energy sources in the EU is large and consists of 67.7% biomass and waste, 19% hydro, 7.7% wind, whilst Poland is mainly concerned with biomass and waste 94.8%, hydro 3.4% and wind energy 1.5 %[12].

Therefore, there is an interest in the cultivation of biocrops in Poland. The plants that are thought of as most promising for energy purposes in Poland are willow and miscanthus [1-3, 19]. The available area in Poland for perennial energy crops amounts to around 1.59 M ha [19]. Bioenergy crops like willow or miscanthus have a large potential to limit the GHG emisions [1, 9].

The increases in N_2O emissions originate from the cultivation and management processes of biocrops. Miscanthus as well as willow, require a low-level input and minimal energy for their production, so that a positive energy balance can be obtained [4, 14, 22]. N_2O production is affected by many physical and biochemical factors, such as nitrate and O_2 concentration, organic matter content, temperature, soil pH and soil moisture content [8, 20].

Carbon sequestration is the process by which agricultural and forestry practices remove carbon dioxide (CO_2) from the atmosphere into a form that does not affect the atmospheric chemistry. A natural way to trap atmospheric CO_2 is by photosynthesis, where carbon dioxide is absorbed by the plants and turned into carbon compounds stored or fixed C as soil organic carbon (SOC). The SOC pool is primarily humus, which is comprised of mixtures of plant and animal residues at various stages of decomposition as well as microbial by-products [15]. Some agricultural management practices will lead to a net sequestration of carbon in the soil [18, 23]. None tillage practices increase the aggregate stability and promote the formation of recalcitrant SOM fractions within stabilised micro- and macroaggregate structures[17]. None tillage practices have a sequestration potential of 0.3 [25] up to 0.4 t C ha^{-1} yr^{-1} [13, 21]; set-aside practises has a sequestration potential of 0.4 t C ha^{-1} $year^{-1}$, whilst avoiding deep ploughing has a potential of 1.4 to 4.1 t C ha^{-1} yr^{-1} [13]. However, the net effect of tillage on C sequestration depends on regions, soil taxonomy, soil texture and climatic conditions [6]. Moreover, without adequate fertilisation, the adoption of none tillage practises will not necessarily increase the carbon sequestration in the soil [7].

Methods

To estimate the soil organic carbon dynamics, greenhouse gas emissions, and potential yield of miscanthus and willow, the DeNitrification-DeComposition Model (DNDC) was used. A simulation was conducted for the most typical soil type suitable for production in Poland.

Model calibration: The model was calibrated based on results from two Experimental Stations of the Institute of Soil Science and Plant Cultivation in Osiny and Grabow (Central Poland). The field experiment was established in 2003. The experimental Station in Osiny is located in the Lublin Voivoideship (51°28'21.28" N and 22°03'09.78"E) on heavy black soil (complex 8 – cereal-fodder strong). The Experimental Station in Grabow is located in the Mazowieckie Voivoideship (51°21'07.64" and N 21°39'46.34" E) on medium-heavy soil (complex 4 – very good rye). The distance between these two experimental sites is about 30 km. The sizes of the individual experimental plots ranged from 200 to 700 m^2. Fertilisation with NPK-fertiliser and ammonium nitrate of tested plants was used in doses given in Table 1. Fertilisation was applied each year in early spring (Table 1).

Table 1. Energy crops production data for DNDC model calibration [1].

Crop	Yield (t d.m./ha)		Plant density (thousand ha)	Fertilisation (kg ha)		
	Clay loam	Sandy loam		N	P	K
Miscanthus	18	15	15	75	22	62.25
Willow	12	13	40	75	50	75

Climate data: The calculations in the DNDC model were done with the 99-year stochastic synthetic weather series prepared for the Grabow agroclimatic weather stations for temporal climate (1971-2000) and climate scenarios for 2030 and 2050.The climate data from the Grabow agroclimatic weather station can be considered as representative for the climate conditions of central Poland. One of the field experiments used for the calibration of the DNDC model with willow and miscanthus were carried out in Grabow.

The 99-year stochastic weather series were prepared as part of the activity within the COST734 action "Impact of climate change and climate variability on European agriculture" (www.cost734.eu). All calculations regarding synthetic data and climate scenarios were prepared and then the data was distributed to the providers of the measurement weather data from local stations for calculation at the Institute of Agrosystems and Bioclimatology, Mendel University in Brno, Czech Republic.

The observed daily weather data between 1971 and 2000 were transformed to a 99-year stochastic weather series of daily parameters using the stochastic weather generator M&rfi [10]. The climate data for 2030 and 2050 were calculated for SRES-A2 IPCC Fourth Assessment emission scenarios [24]. More details on the SRES (Special Report on Emissions Scenarios) may be found in Nakićenović *et al.* [17], and additional details (including model validation) concerning the construction of GDM-based climate scenarios for climate change studies can be found in Dubrovský *et al.* [11]. The climate data used in the study included maximum and minimum temperatures and precipitation sum.

Model: The prediction of the crop yield, soil temperature, moisture regimes, soil carbon dynamics, nitrogen leaching, and emissions of trace gases including nitrous oxide (N_2O), nitric oxide (NO), dinitrogen (N_2), ammonia (NH_3), methane (CH_4) and carbon dioxide (CO_2) were conducted with the DNDC model. The DNDC 9.2 version was chosen in order to achieve the most reliable and stable results. The model was calibrated by using experimental data.

Results and Discussion

Climate change projections: According to the generated data used in the study, the baseline annual air mean temperature (1971-2000) was 8.1°C (C2000, Table 2). Under an climate scenario of C2030 the average annual temperature increased by 1°C, whilst under the 2050 climate scenario it was 1.7°C. Temperature increases were observed during all months, with the highest increases in January (1.6°C for 2030; 2.8°C for 2050), and lowest increases in May (0.5°C for 2030; 0.9°C for 2050, Table 2). The baseline (1971-2000) yearly precipitation mean in Grabow, according to generated data was 631 mm (C2000, Table 3). The yearly mean precipitation for the future climate was simulated to decrease by only 1.0% in scenario C2030, and about 1.2% in scenario C2050. It is very important for crop productivity in Poland to use climate scenarios, as they predict what the increases in the precipitation sum will be in the months from December to May, and decreases in the months from June to November. The highest increase of the precipitation sum was predicted for April (12.9% for C2030, 10.8% for C2050), whilst the highest decrease was in August (-10.9% for C2030, -9.0% for C2050).

Biomass yield change projection: With an increase of temperature and decrease in precipitation, the biomass yield has decreased slightly but still significantly (Fig.1) for willow grown on both types of soil and for miscanthus grown on clay loam soil. The differences of biomass yield between scenarios C2050 and C2000 amounted to 5.3 and 3.3% for miscanthus grown at clay loam and sandy loam respectively, whilst for willow, the yield decreased by 4.5 and 7.1 % on those types of soil.

N_2O emission: A change of the climate according to scenario C2030 and C2050 will influence the decrease of N_2O emissions from miscanthus (both types of soil) and willow (sandy loam) cultivation.

Table 2. The average monthly and annual air temperature during 1971 and 2000 (C2000, °C), and its change (°C) in 2030 (C2030) and 2050 (C2050) climate scenarios according to synthetic data used in the study.

Time series	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
C2000	-2.9	-1.0	3.1	8.0	13.4	16.3	18.0	17.7	13.3	8.6	2.6	-0.5	8.1
C2030	1.5	1.2	0.9	0.7	0.5	0.7	0.8	1.0	1.0	1.1	0.9	1.3	1.0
C2050	2.8	2.1	1.6	1.2	0.9	1.3	1.5	1.8	1.7	2.1	1.6	2.4	1.7

Table 3. The average monthly and annual sum of precipitation during the years 1971 and 2000 (mm) and its change (%) in 2030 and 2050 climate scenarios according to synthetic data used in the study.

Time series	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
C2000	30.4	26.2	35	40.3	63.8	82.4	82.5	72.4	70.8	50	41	36.9	631.6
C2030	5.	7.3	6.0	12.9	3.6	-0.7	-6.1	-10.9	-8.6	-0.8	-4.1	6.0	-1.0
C2050	4.7	5.7	4.9	10.8	2.6	-0.2	-4.6	-9.0	-6.8	-0.8	-3.1	4.3	-0.4

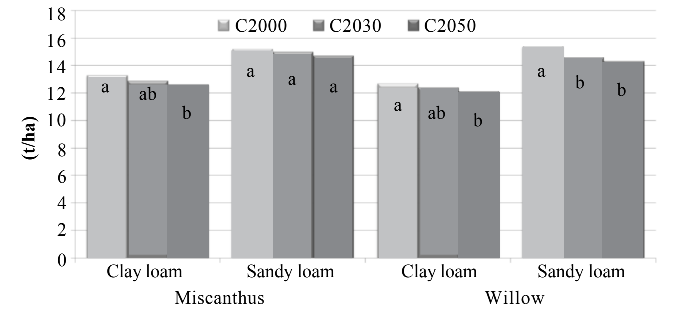

Figure 1. Potential yield level from willow and miscanthus cultivations. (treatments with the same letters do not show a statistically significant difference).

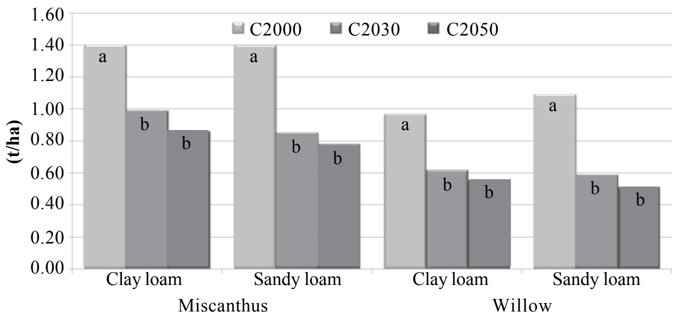

Figure 3. Carbon sequestration levels under Willow and Miscanthus cultivation (treatments with the same letters do not show a statistically significant difference).

Average N_2O emissions, estimated for those crops using the DNDC model were different for each climate scenario, plant and soil type. In the C2030 scenario with an increase of temperature by 1°C and a decrease in precipitation by 1%, the biggest decrease in N_2O emissions was by 80% compared with the C2000 scenario and was calculated for miscanthus grown on clay loam. A significant reduction in N_2O emissions (70%) was also calculated for miscanthus grown on sandy loam and for willow cultivated on sandy loam soil (59%). A further increase of temperature and a decrease of precipitation in the C2050 scenario results in a reduction of N_2O emissions by approx. 15% for willow grown on clay loam, whilst for willow grown on sandy loam it decreases by a further 7% related to the C2030 scenario (Fig. 2). However, the future increase of temperature and precipitation in the C2050 scenario saw no continuation of a reduction in the N_2O emission under miscanthus cultivation on both types of soil, as it rose on both types of soil as compared to the C2030 scenario.

The reduction of N_2O emissions from those cultivations was due to a lower precipitation during the summer months.

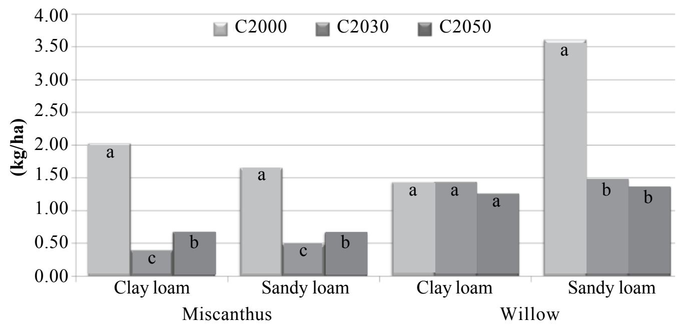

Figure 2. Emission levels of nitrous oxide (N2O) from willow and miscanthus cultivation (treatments with the same letters do not show a statistically significant difference).

Carbon sequestration potential: Bioenergy crops are characterised with a high potential for carbon mitigation. However, different authors found that the carbon sequestration rates for these cultivars are different. Willow cultivations can be sequestered at 0.15-0.22 t C ha^{-1} yr^{-1}, whereas in miscanthus cultivation they were 0.13-0.20 t C ha^{-1} yr^{-1} [5]. According to Matthews and Grogan [16], 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^{-1} yr^{-1}. The net soil carbon sequestration in miscanthus crops was around 0.38-0.95 t C ha^{-1} yr^{-1} and 0.22-0.39 t C ha^{-1} yr^{-1} for willow [1].

According to our simulations, climate change has a negative impact on the carbon sequestration potential under biocrop cultivation grown in the studied soils. Miscanthus has a higher potential for sequestrate soil carbon than willow. The reduction of carbon sequestration due to climate change was smaller by approx. 22-37% under miscanthus as compared to willow.

Conclusions

The climate change perspective for 2030 and 2050 showed a rather small but significant decrease on the yield level for miscanthus and willow in Poland, with significant changes in the potential of C sequestration and reductions of the nitrous oxide emission level.

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