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LONG TERM YIELDS AND GAS EMISSIONS FROM POPLAR AND WILLOW GROWN ON AGRICULTURAL LAND IN DEPENDENCE TO NITROGEN FERTILIZATION

ŽEMĖS ŪKIO PASKIRTIES ŽEMĖJE AUGINTŲ TUOPŲ IR GLUOSNIŲ ILGALAIKIO DERLINGUMO IR DUJŲ EMISIJŲ PRIKLAUSOMYBĖ NUO TRĘŠIMO AZOTO TRĄŠOMIS

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The production of biomass for energy has been intensified worldwide during the last years. However, its potential to face climate change is far away to be fully used yet. Agricultural energy crop cultivation removes CO_2 from atmosphere and thermal conversion of these crops can replace fossil fuels. This form of CO_2-neutral energy supply however might be constrained by other greenhouse gases, which are released during the production and consumption of energy crops. Poplar and willow are very promising energy crops for farmers due to their high productivity and low demand on inputs such as of fertilizer and labour. To evaluate the whole process chain of field wood cropping, different plantations have been established on a loamy sand soil in Northeast of Germany in 1994 and 2008. The measuring program of the long-term practical oriented field experiment started in 1994 includes yields, energy gain, N_2O emissions as well as ecologically relevant plant and soil constituents. Three different fertilization rates (0, 75, and 150 kg N ha^{-1} yr^{-1}) have been investigated for poplar (*P. maximovizcii x P. nigra*) and willow (*Salix viminalis*). Based on the results of this experiment a second experiment with reduced fertilization rates with poplar and willow arranged in a random block design has been started in 2008. The focus of this experiment is on nitrogen flux. Nitrogen fertilization led to leaching of nitrogen in all tests. The application of 75 kg N ha^{-1} yr^{-1} caused an average increase of N leaching in the willow and poplar plots of 25 kg N ha^{-1} yr^{-1} and 40 kg N ha^{-1} yr^{-1}, respectively. Furthermore, all results indicate a more effective and environmentally sound field wood production without the use of mineral nitrogen fertilizer and a low influence of fertilization on yields.

Bioenergy, poplar, willow, yield, fertilization, N_2O, nitrogen.

Introduction

Bioenergy has a key role in current German and EU strategies for climate protection and security of energy supplies. Energy crop production removes CO_2 from atmosphere and thermal conversion of these crops can replace fossil fuels. This form of CO_2-neutral energy consumption however might be constrained by other greenhouse gases, which are released during the production and utilisation of energy crops (Jorgensen et al. 1997, Crutzen et al. 2007). Energy farming on surplus agricultural area presents an opportunity to create alternative income sources besides food production, to strengthen added value and employment in rural areas (Scholz et al. 2009). In general, energy crops should have characteristics like high yields, low production inputs and high energy values to make the production of energy from biomass even more economically efficient and to optimise the environmental benefits.

Nitrogen fertilization is an important factor for efficient crop production. But then, nitrogen applied as fertiliser to increase the biomass yield induces the emission of N_2O. This GHG may play a key role in a life cycle assessment due to its high global warming potential. Average values for N fertiliser induced N_2O emission factors are reported for agricultural fields and grassland with a range of 0.5 to 5% (IPCC 2006). Relatively low values have been found for short rotation coppices (SRC) (Hellebrand et al. 2008, Kern et al., 2010).

The objective of this study is to prove whether reduced nitrogen fertilisation may influence the yield of woody biomass on a site with low supply of nutrients and water. Among the environmental drawbacks during the production of willows and poplars, nitrous oxide emissions have been analysed to optimise the fertilisation with nitrogen and to reduce environmental impacts during the production of energy crops.

Materials and Methods

In order to select environmentally friendly plant species and cropping technologies two different field experiments has been established Northwest of Potsdam on a loamy sand soil (Scholz et al. 2001, Kern et al. 2012). The field for the first experiment E1 (established in 1994) is divided in plots of 0.25 ha cultivated with willow (*Salix minimalis* 12/21/83) and poplar (*Populus maximovizcii x P. nigra*, Japan 105 and *Populus maximowiczii x P. trichocarpa*, NE42). In April 1994 the test cuttings were planted in double rows (distance 0.75 m) with 0.55 m distance in the row and with 2.25 m distance between the double rows. For the detailed analysis of the influence of fertilisation on yield and emissions the field is subdivided in 4 blocks (A-D) with 624 m^2 each. Block A receives basic mineral fertilisation and 150 kg N/ha. On blocks B and C 75 kg N/ha are applied in form of wood- and straw ashes. Block D is not fertilised. On the entire area, no plant protection products are used (Fig. 1). As fertilisers, 540 or 270 kg/ha of calcium-ammonium nitrate and 520 kg/ha of potash-magnesia/super-phosphate mixture, as well as 660 kg/ha of coarse ashes each from a wood- and a straw combustion plant are used (Scholz et al. 2001; Scholz et al. 2002). Furthermore, the influence of harvest cycles of 2 and 4 years on yields is investigated.

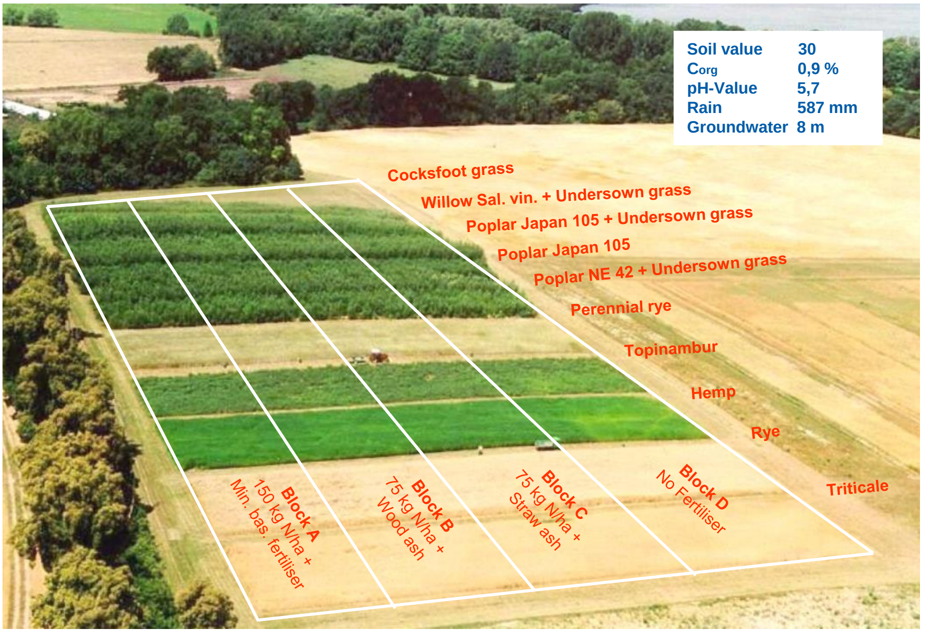

Fig. 1. Experimental field E1 at the ATB (long term experiment since 1994)

1 pav. ATB įrengti eksperimentiniai laukeliai E1 (ilgalaikiai eksperimentai nuo 1994 m.)

For the second experiment E2 (established in 2008), a randomized block-design was chosen with four replicates. Poplar (*Populus maximovizcii x P. nigra*, clone Max 4) and willow (*Salix viminalis*, clone Inger) treatments are examined in terms of yield, N_2O emissions as well as nitrate leaching. The experiment consists of three N-fertilisation treatments (0, 50, and 75 kg N ha^{-1} yr^{-1}) investigated on two square large-plots with 1800 m² each (see Figure 2). The subplots have a size of 9 m x 10 m. In April 2008 the test cuttings were planted with 0.5 m distance in the row and with 1 m distance between the rows. To minimise boundary effects, only 48 internal plants of each plot were examined. At the beginning of each vegetation period (June 2008, April 2009-2012), nitrogen was applied in form of calcium ammonium nitrate (CAN). In the winter of 2009 the aboveground biomass was harvested with a brush cutter. A second harvest has been done after 2 years in winter 2011.

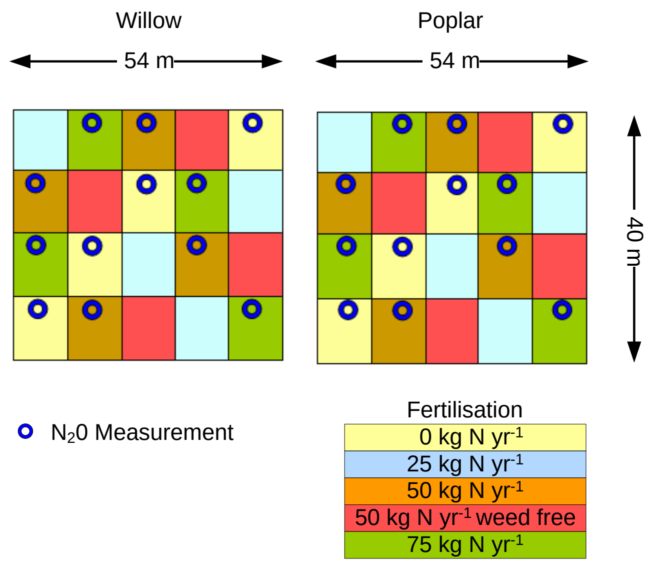

Fig. 2. Experimental field E2 at the ATB (new experiment since 2008)
2 pav. ATB įrengti eksperimentiniai laukeliai E2 (nauji eksperimentai nuo 2008 m.)

Furthermore, the area-related nitrate leaching rate has been measured at experimental field E2. Self-Integrating Accumulators (SIAs) filled with a resin-quartz sand mixture were installed at a depth of 90 cm below the main root zone of willow and poplar trees according to Bischoff (2009). The SIA remained in the soil for half year periods, collecting and adsorbing nitrate from the leachate before being excavated and analysed.

The investigations of the nitrous oxide emissions were started in 1999 for the experiment E1 and in June 2008 for the experiment E2 and were conducted four times a week. The soil incubation took place in-situ in closed chambers for 90 minutes in the morning. The incubation was followed by a gas-chromatographic analysis, with a detection limit of N_2O for $5x10^9$ ml, as described by Hellebrand et al. (2003).

Results and Discussion

Yield: The yield is the most important parameter determining the environmental and energetic efficiency of the production of energy crops. Related to the measuring period of 10 to 17 years the highest dry matter (DM) yields in total were measured in experiment E1 on the poplar plot Japan 105 with an average of 11.5 t_{dm} ha^{-1} yr^{-1} (2 year harvest cycle). The undersown grass seems to have no influence on yields after the first 10 years (Figure 3). The yield averages over the whole investigation period of 19 years are 9.0 t_{dm} ha^{-1} yr^{-1} for the trial with undersown grass resp. 10.4 t_{dm} ha^{-1} yr^{-1} without grass.

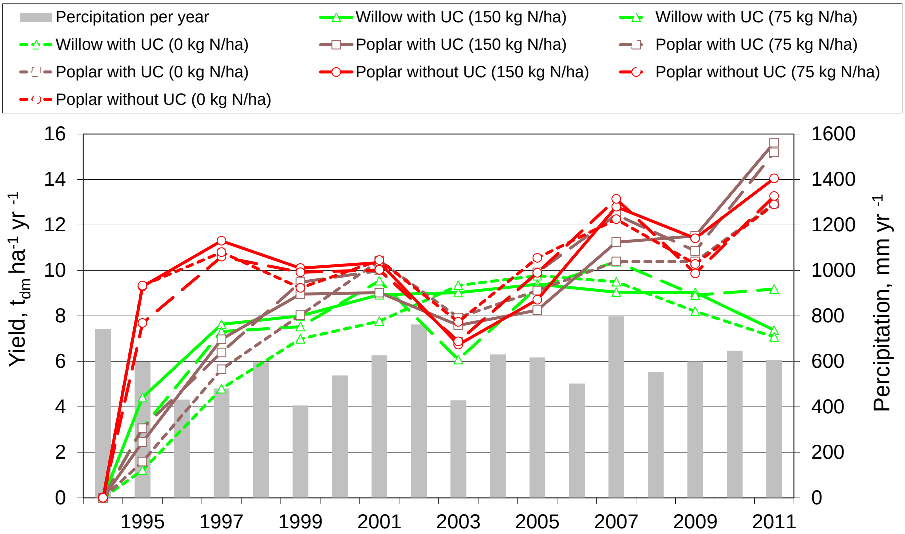

Fig. 3. SRC Yield in experiment E1 (long term experiment since 1994, 2 year rotation cycle)

3 pav. Trumpos rotacijos želdinių derlius eksperimentiniuose laukeliuose E1 (ilgalaikiai eksperimentai nuo 1994 m., dviejų metų rotacijos ciklas)

The measuring period of experiment E2 is comparably short and maximum yields of 6.2 t_{dm} ha^{-1} yr^{-1} has been measured for poplar resp. 4.6 t_{dm} ha^{-1} yr^{-1} for willow (Figure 4).

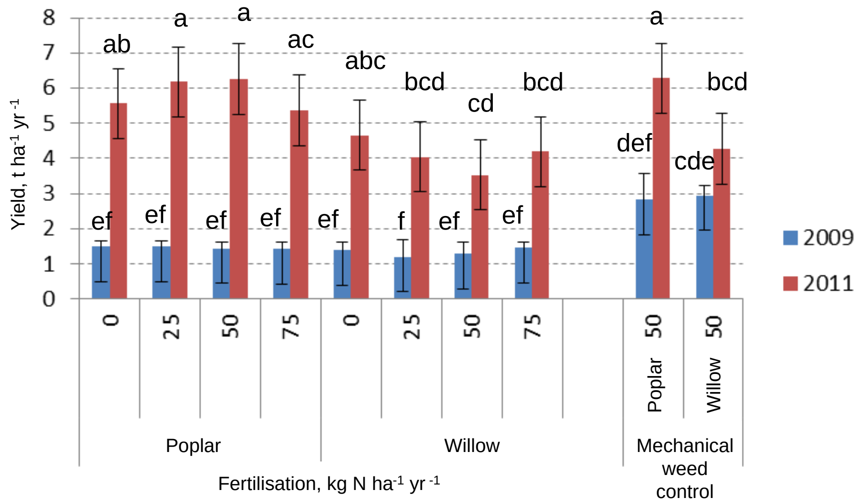

Fig. 4. SRC Yield in experiment E2 (new experiment since 2008)

4 pav. Trumpos rotacijos želdinių derlius eksperimentiniuose laukeliuose E2 (nauji eksperimentai nuo 2008 m.)

Fertilizer-Induced Emissions: There are two sources of gaseous emissions caused by fertilisers. The first one is the concentration of emissions relevant substances in plants such as nitrogen, phosphorus, sulphur and chlorine. They lead e.g. to an increase of nitrous oxide emissions (NO_x) of 10 to 50 mg/m³ during combustion (Obernberger 1997), which is significant compared with legal limits in the range from 250 to 400 mg/m³.

The other source of gaseous emissions caused by nitrogenous fertiliser occurs on the field. As a result of the activity of microorganisms the nitrogen forms nitrous oxide (N_2O), which global warming potential is about 300 times more effectively than CO_2. As shown by gas measurements, carried out on the mentioned experimental field E1 over several years, the application of 150 kg N/ha causes an additional quantity of up to 2 kg N_2O-N per hectare and year to be emitted from the soil (Hellebrand, Kern, Scholz 2003). There is also an influence of the plant species, which partially may be explained by the soil management. Poplar and willow cause significantly less N_2O emissions than common field crops such as cereals. For instance, non-fertilised SRC fields emit only 15 to 30% N_2O of conventionally fertilised rye field (Fig. 5).

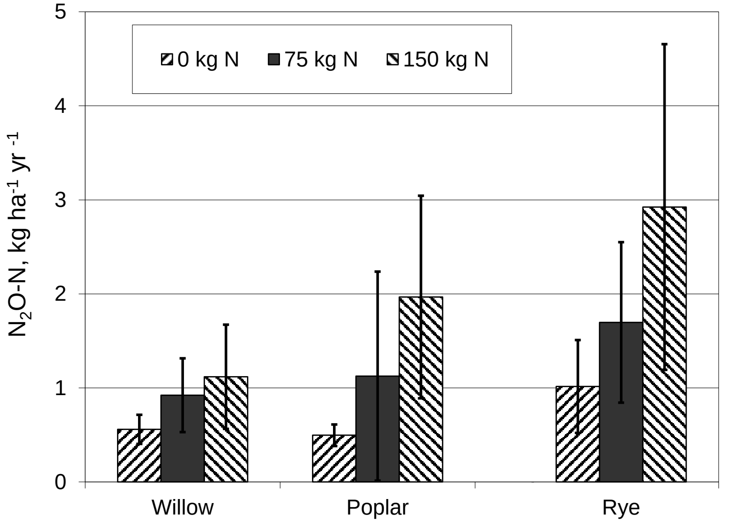

Fig. 5. Long-term N_2O emissions of SRC and rye at experiment E1 (1999-2007)

5 pav. Trumpos rotacijos želdinių ir rugių N_2O emisijų ilgalaikiai tyrimai eksperimentiniuose laukeliuose E1 (1999-2007 m.)

Results from the field experiment E2 show the same trends for N_2O emissions.

With increased nitrogen fertilisation the rates of N_2O emission increased during this time (Figure 6). In the plots with 50-75 kg N ha-1 yr-1 the mean fertiliser induced emission are approx. 34 % higher for willow resp. 13 % for poplar.

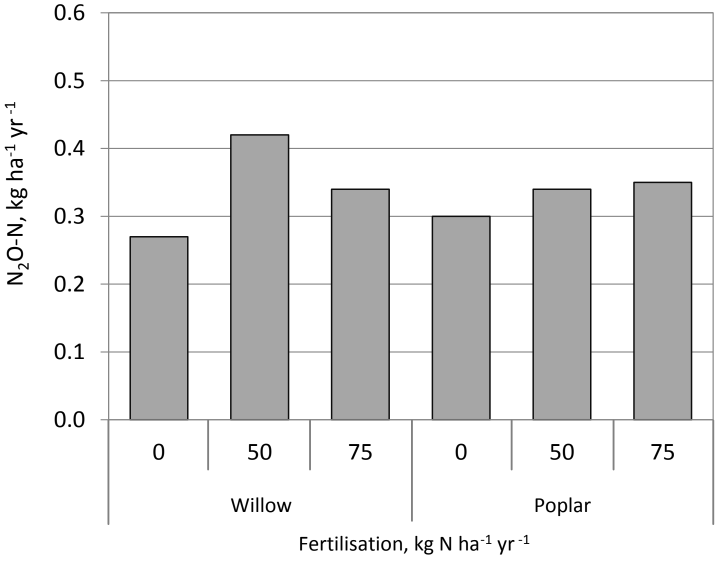

Fig. 6. N_2O emissions of SRC at experiment E2 (2008-2012)

6 pav. Trumpos rotacijos želdinių N_2O emisijų tyrimai eksperimentiniuose laukeliuose E2 (2008-2012 m.)

Figure 7 shows the balance of the nitrogen input by atmospheric deposition and nitrogen fertilisation as well as the output of nitrogen due to the removal by harvested crop, leaching and emissions of N_2O. A further loss of N_2 due to denitrification has to be taken into account, which is not reflected by this picture. The amount of nitrogen incorporated into shoot biomass was only 14-34 % of the applied fertiliser corresponding with results given by Jug et al. (1999). The nitrogen demand of willow and poplar was met by 46-70 % by deposition, which implies that the soil under study is sufficiently supplied with a low rate of nitrogen fertilisation.

Leaching rates of nitrate were higher in poplar than in willow plots. Highest leaching rates were measured at fertilisation rates of 75 kg N ha^{-1} yr^{-1} resulting in an increase of N leaching of 25 kg N ha^{-1} yr^{-1} for willow and 40 kg N ha^{-1} yr^{-1} for poplar. It could be shown in this study that the major path of nitrogen applied as fertiliser was lost by leaching. In contrast to the leaching loss, the nitrous oxide emissions, induced by fertilisation, were rather small. Another significant fate of nitrogen fertiliser was the increase of weed biomass primarily in the willow plots. The weed in the highest fertilised treatments contained additional 25 kg N ha^{-1} yr^{-1}.

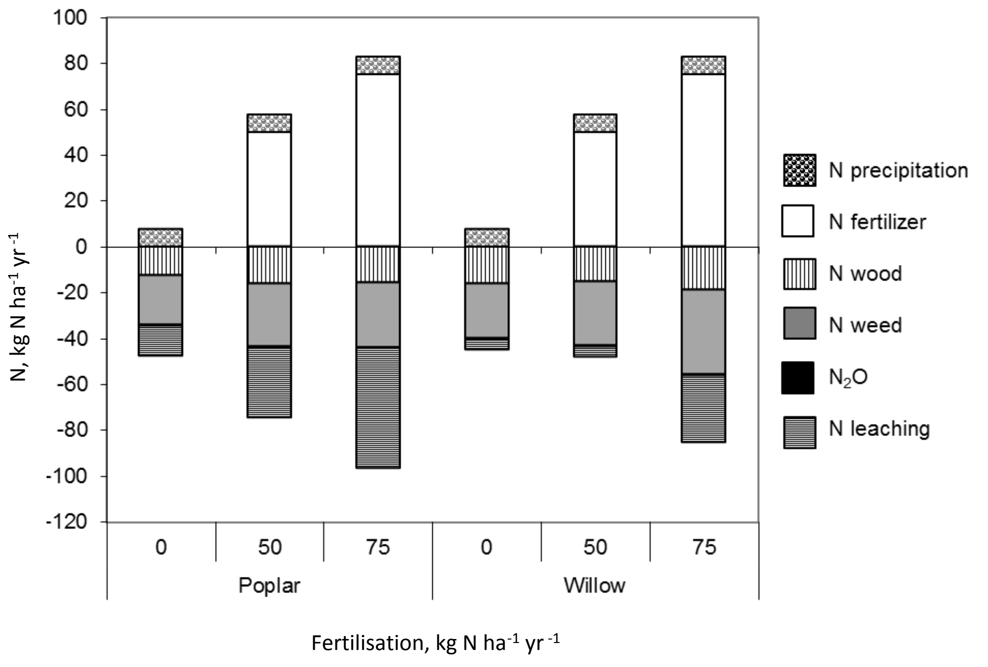

Fig. 7. Nitrogen balance in a Short Rotation Coppice during the initial stage 2008-2010.

7 pav. Azoto balansas trumpos rotacijos želdiniuose pradinėje augimo stadijoje 2008-2010 m.

Conclusions

Reducing the input of nitrogen fertilisers to arable land does not result in a significant decrease in biomass yield, but it has positive effects on the environment. Moreover, from an environmental, energetic and economic point of view, the application of high fertilizer rates is generally inefficient.

Long term test have shown, that yields of SRC were reduced only within the first 5 to 10 years. Later there is nearly no difference between the blocks. The reasons of this ecologically very useful phenomenon are not clarified up to now.

Cropping SRC is one way of mitigating direct and indirect greenhouse gas emissions including those CO_2 equivalents required for the production of mineral nitrogen fertilisers. Further research is needed to specify the excellence of the perennial energy crops and to enhance the distribution of poplar and willow in agriculture.

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Ralf Pecenka, Antje Balasus, Volkhard Scholz, Jürgen Kern, Hannes Lenz

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Santrauka

Pastaraisiais metais biomasės gamyba energijos reikmėms suintensyvėjo visame pasaulyje, tačiau biomasės potencialas nevisiškai panaudojamas spręsti klimato kaitos problemoms. Auginant žemės ūkio energetinius augalus iš atmosferos pašalinamas CO_2 ir paverčiant šiuos augalus į šiluminę energiją jais galima pakeisti iškastinį kurą. Šis CO_2 požiūriu neutralus energijos gamybos būdas gali būti ribojamas dėl kitų šiltnamio efektą sukeliančių dujų, kurios išsiskiria ruošiant ir naudojant energetinius augalus. Tuopos ir gluosniai yra labai perspektyvūs energetiniai augalai ūkininkams dėl didelio jų derliaus ir mažų trąšų ir darbo jėgos sąnaudų. Norint įvertinti visą lauko medienos auginimo procesą, 1994 ir 2008 metais šiaurės rytų Vokietijoje priesmėlio dirvožemyje buvo įveistos įvairios augalų plantacijos. 1994 metais pradėta naudoti lauko bandymams skirta ilgalaikė tyrimų programa, pagal kurią buvo vertinamas energijos padidėjimas, N_2O emisijos, taip pat ekologiniu požiūriu svarbios augalų ir dirvožemio sudedamosios dalys. Tirtos trys skirtingos trąšų normos (0, 75 ir 150 $kg \cdot N \cdot ha^{-1}$ per metus) auginant tuopas (P. *maxi-movizcii x p nigra*) ir gluosnius (*Salix viminalis*). Remiantis šio bandymo rezultatais, 2008 metais buvo pradėtas antras eksperimentinis tyrimas, kurio metu atsitiktine tvarka išdėstyti tuopų ir gluosnių laukeliai buvo tręšti sumažintomis trąšų normomis. Šio bandymo metu daugiausia dėmesio buvo skirta azoto kitimui. Azoto trąšų kiekis lėmė azoto išplovimą atliekant visus bandymus. Naudojant 75 $kg \cdot N \cdot ha^{-1}$ trąšų normą per metus, azoto išplovimas gluosnių ir tuopų sklypeliuose vidutiniškai padidėjo po 25 $kg \cdot N \cdot ha^{-1}$ ir 40 $kg \cdot N \cdot ha^{-1}$ per metus. Be to, pagal visus rezultatus efektyvesnė ir mažiau kenksminga aplinkai lauko medienos gamyba nenaudojant mineralinių azoto trąšų, taip pat maža tręšimo įtaka augalų derliui.

Bioenergetika, tuopos, gluosniai, derlius, tręšimas, N_2O, azotas.

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ЗАВИСИМОСТЬ МНОГОЛЕТНЕЙ УРОЖАЙНОСТИ И ГАЗОВЫХ ЭМИССИЙ ОТ ПРИМЕНЕНИЯ АЗОТНЫХ УДОБРЕНИЙ ПРИ ВЫРАЩИВАНИИ ТОПОЛЕЙ И ИВ НА ЗЕМЛЯХ СЕЛЬСКОХОЗЯЙСТВЕННОГО НАЗНАЧЕНИЯ

Резюме

В последние годы в мире заметно увеличилось производство биомассы для использования в энергетических целях. Однако потенциал биомассы далеко не полностью использован на нынешнем этапе решения проблем по

улучшению условий окружающей среды. При выращивании энергетических растений из атмосферы удаляется CO_2, а в результате термической конверсии можно заменить значительное количество минерального топлива. Однако этот нейтральный по CO_2 эмиссиям вид производства энергии оборачивается отрицательным эффектом при дальнейшей подготовке и использовании. Тополь и ива являются очень перспективными энергетическими растениями из-за высокой урожайности биомассы, низких затрат при выращивании и потребности к удобрениям. Для полной оценки процесса выращивания биомассы этих растений в 1994-2008 гг. в северо-восточной части Германии на песчаной почве были разведены плантации тополя и ивы. В 1994 г. была составлена долгосрочная программа исследований для определения динамики роста энергетической ценности этих растений, изменения N_2O и влияния на качество почвы в экологическом аспекте. Исследовались три разные годовые нормы внесения удобрений (0, 75 и 150 $кг \cdot N \cdot га^{-1}$) при выращивании тополей (*P. maximovizcii x p nigra*) и ив (*Salix viminalis*). Согласно полученным результатам, в 2008 г. был начат второй эксперимент на участках со случайным расположением тополей и ив. Применялись уменьшенные нормы азотных удобрений. Во время опытов основное внимание уделялось динамике изменения количества азота в почве. Установлено, что спустя год остаток азота на участках с растениями уменьшился на 25 $кг \cdot N \cdot га^{-1}$ и 40 $кг \cdot N \cdot га^{-1}$ соответственно по сравнению с начальными нормами внесенных удобрений (75 $кг \cdot N \cdot га^{-1}$). Это объясняется тем, что удобрения вымываются водой. Обобщая результаты исследований, можно утверждать, что применение минеральных удобрений нецелесообразно из-за малого влияния на урожайность биомассы и отрицательного влияния на почву и грунтовые воды.

Биоэнергетика, тополь, ива, урожай, внесение удобрений, N_2O, азот.