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CHAPTER IX

Janusz Augustynowicz[1], Stefan Pietkiewicz[2], Mohamed Hazem Kalaji[2], Stefan Russel[3]

THE EFFECT OF SLUDGE FERTILIZATION ON CHOOSEN PARAMETERS OF CHLOROPHYLL FLUORESCENCE AND BIOMASS YIELD OF JERUSALEM ARTICHOKE (*HELIANTHUS TUBEROSUS* L.)

Introduction

According to 2001 EU Directive related to the Promotion of Electricity produced from Renewable Energy Sources in the internal electricity market, each member states of European Union should reach till 2010 r. a 12 % contribution of renewable sources energy gross use, while the whole Community 22,1 %. Polish Development Strategy of Renewable Energy Sector adopted by the Parliament of the Republic of Poland (2001) promotes development of renewable energy sources in our country and indicates basic goals as well as conditions of renewable energy development in Poland till 2020. There is an assumption to increase of the share of energy from renewable sources in the whole country fuel-energy balance up to 7,5% (340 PJ) in 2010 and to 14% in 2020. It means three times increase as compared to 1999 (2,5% – 105 PJ). Converting biomass is one of a processes to get renewable energy by the use of energy crops such as e.g. Jerusalem artichoke, Virginia mallow, Giant Knotweed, Common osier, Reed Canarygrass, Miscanthus Giganteus and others (Augustynowicz et al. 2008).

During the last few years an increase interest of energy crops Jerusalem artichoke (*Helianthus tuberosus* L.), also known as topinambura is observed. This plant originates from Northern America and belongs to the family *Asteraceae* (Majtkowski 2003). Stems of topinambur of up to 3 cm diameter are 2 – 4 m tall. Analyzed species forms underground stolons, bearing at their tips tubers (same as with potato). The raw material for energy purposes are both tubers, which can be used for bioethanol or biogas production as well as above ground parts: fresh or fermented – for biogas production, dry – for direct combustion of fragmented mass or to produce briquettes and pellets (Majtkowski 2003, Stolarski 2004).

Topinambur is a crop of very high production potential (Kays, Nottingham 2007). Its yielding is determined first of all by genotype, but the soil culture and content has also a significant effect. Same as with root and tuber crops the best for topinambur cultivation are soils midloosed, aerated, rich in mineral nutrients and having enough moisture. It can be also cultivated in the worse site, less profitable for potatoes. There is no way to cultivate this crop in marsh and acid soils. All crops can serve as a forecrop for it, even some small weeded fallows, nevertheless it requires deep ploughing (20-30 cm). Topinambur can be cultivated in the same stand for 3-4 years (STOLARSKI, 2004). In one of the national experiments total biomass yield was ca 110 $t \cdot ha^{-1}$: above ground mass 75,6 $t \cdot ha^{-1}$, tubers 32,4 $t \cdot ha^{-1}$ (STOLARSKI, 2004). The yielding in this experiment was much higher on polish soil bonitation class III as compared to class IVb. Under polish conditions average field of topinambur on dry matter basis is 10-16 t $d.m. \cdot ha^{-1}$ (MAJTKOWSKI 2003, STOLARSKI, 2004). High yielding potential, easy cultivation, low cost of launching plantation and big abilities of adaptation to soil conditions, speak for further dissemination of this crop, this time however, as an energy crop, in Poland (MAJTKOWSKI 2003). A real possibility to obtain high yielding, being the costs low, is the principal cause of increased interest in this crop GRADZIUK 2003). The goal of research on energy crops aim to elaborate such a way of its cultivation to reach maximum biomass increase. There are two ways of cultivation: traditional, providing nitrogen from such its conventional sources as mineral fertilizers or new, using as its source such inconvenient for environment waste, as sludge (AUGUSTYNOWICZ et. al. 2008).

Restoration to soil mineral nutrients from sludges seems to be adequate not only from economic point of view, but also is necessary to maintain and renew ecological homeostasis. Mineral and organic composition of residuals from municipal wastewater treatment plant is proximal to a soil organic substance – a humus (BĄCZALSKA 1998). So, there is possible natural, with this agricultural use, of the Sludges. The sue of the latter in non industrial way should meet needs concerning their chemical composition and sanitary state. Heavy metal contents in sludges for non industrial use is limited due to their toxic influence on living organisms and ability for bioacumulation (BIEŃ 2002).

Plant physiology offers many physiological parameters to be exploited in different plant science fields. Some physiological issues such as the photosynthetic efficiency of plants have started to be investigated to evaluate the performance of crops when growing under various environmental and growth conditions. One of these parameters is chlorophyll fluorescence which indicates the capacity of plants to convert light energy to biochemical energy during the photosynthetic process. The advantages of this technique are that, it is non-invasive, non-destructive and rapidly measured using highly portable equipment. Many scientists have already applied this technique in their researches as a biomarker or bioindicator and proved that it provides reliable information about plant photosynthetic efficiency which is highly correlated to plant vitality (KALAJI I and GUO 2008).

The aim of the paper was to analyze the effect of fertilization with sludges from municipal wastewater treatment plant on activity of photosynthetic apparatus of Jerusalem artichoke (*Helianthus tuberosus* L) as crop claimed to be the most promising energy crops for Poland.

Research conditions

In 2007, in the Institute of Land Reclamation and Grassland Farming Falenty near Warszawa a two factorial field experiment in randomized blocks design with three replicates was conducted. Each replicates involved 9 plants. The following treatments were used:

1. control (no nitrogen fertilization) („0”),
2. 100% N sludge, 0% N mineral fertilizer (100% sludge),
3. 75% N sludge, 25% N mineral fertilizer (75% sludge),
4. 50% N sludge, 50% N mineral fertilizer (50% sludge),
5. 25% N sludge, 75% N mineral fertilizer (25% sludge),
6. 0% N sludge, 100% N mineral fertilizer (0% sludge).

An equivalent of 170 $kg \cdot ha^{-1}$ pure nitrogen was used as fertilization in treatments with sludges. The used nitrogen rate was established according to the acceptable maximum resulting from the Act on Fertilizers and Fertilization (2000, 2004). The sludge was provided by communal wastewater treatment plant Falenty. The sludge meets all requirements concerning possibility its use in agriculture. The chemical indices that characterize used sludge presented in table 1.

Table 1

Characteristics of sludge chemical composition

Analyzed index	Unit	Result
pH in water	pH	12.7
Dry matter content	%	22.73
N total	% dry matter	2.93
P_2O_5	% dry matter	3.79
K_2O	% dry matter	0.41
Cd	$mg \cdot kg^{-1}$ dry matter	0.94
Cr	$mg \cdot kg^{-1}$ dry matter	16.7
Cu	$mg \cdot kg^{-1}$ dry matter	104
Ni	$mg \cdot kg^{-1}$ dry matter	15.6
Pb	$mg \cdot kg^{-1}$ dry matter	19.8
Zn	$mg \cdot kg^{-1}$ dry matter	603
Hg	$mg \cdot kg^{-1}$ dry matter	0.57

Each additional treatment, 0 treatment involving, was enriched with mineral potassium fertilizer 240 kg $K \cdot ha^{-1}$. Its rate was established on the basis of the crops nutritional needs and potassium content in sludge.

The experiment was performed on the soil classified as black earth degraded. Parameters that characterized this soil presented in table 2.

Table 2

Characteristics of soil for Jerusalem artichoke cultivation in Falenty

Level	Depth [cm]	pH		Total in %		C : N
		H_2O	KCl	C	N	
A	0-30	5.16	4.71	1.38	0.09	15.33
C	30-60	5.05	4.8	2.38	0.15	15.86
Ak	60-80	5.83	5.18	1.01	0.04	25.25
C	80-150	5.84	5.16	0.47	0.02	23.50

Measurements of physiological indices that characterize photosynthetic apparatus of topinambur performed in 3 terms July 2, August 2 and October 17. The following indices of physiological activity of the apparatus were used: index of photosystem II (PSII) functioning and vitality (*Performance Index,* P.I.) and maximum quantum yield of PSII (F_V/F_M). These indices are recommended by Kalaji and Łoboda (2007, 2009) as the best indicators of photosynthetic apparatus efficiency measured with detection and analysis of chlorophyll *a* fluorescence signal technique. There were determined with the use of HandyPEA fluorimeter (Hansatech Instruments, King's Lynn, Norfolk, UK).

The above mentioned parameters of chlorophyll *a* fluorescence were measured for three layers of the canopy (upper, middle and lower) in 3 replicates for each treatment. At harvest, on 25 XI biomass field of Jerusalem artichoke was determined. The results were statistically analyzed with the use of SAS 9.1. version.

Indices of Jerusalem artichoke photosystem II functioning

Figure 1 presents data which characterize changes of global Performance Index PSII (P.I) of topinambur fertilized with sludge during vegetation. The highest P.I. values were reached in middle period of vegetation of the analyzed crop – the index is about 5 units. In July the sludge used caused a decrease of analyzed index as compared with that of 100% share of mineral fertilizer. In August the value of P.I. increased for treatments with sludge, the highest values being for treatments with z 50% and 75% share of sludge nitrogen. At the end of vegetation the sludge clearly stimulated an increase in activity of photosynthetic apparatus of studied crop. Similar data reported AUGUSTYNOWICZ et al. (2008).

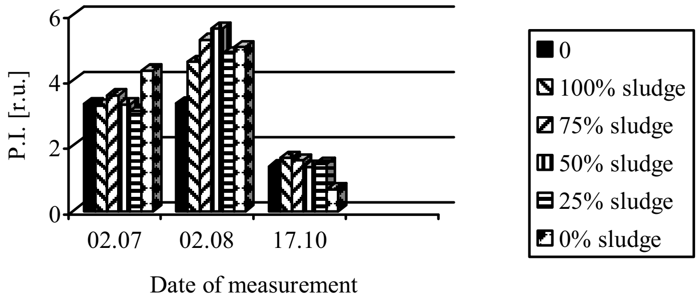

Fig. 1. Changes of global Performance Index (P.I.) of Jerusalem artichoke fertilized with a sludge during vegetation

In the case of upper layer of canopy the values of Performance Index (P.I) on 2.07 showed the use sludge increased activity of photosynthetic apparatus for treatment with 75% share of sludge nitrogen in the applied nitrogen rate (Fig. 2A). The data of measurements made one month later (2.08) indicated a similar tendency of sludge affecting on the index of photosynthetic apparatus efficiency. The highest values P.I. were found for treatment with 50% share of sludge nitrogen. Measurements in autumn (17.10) showed significant decrease in activity of photosynthetic apparatus for treatment 100 % share of mineral nitrogen as compared to those where the sludge without mineral nitrogen was used.

Data obtained on 2.07 for central layer of the canopy layer showed the use of sludge caused a decrease in Performance Index of PSII when compared to the treatment containing the sole mineral nitrogen (Fig. 2B). On 02.08 activity of photosynthetic apparatus of Jerusalem artichoke was the lowest for the control treatment (a slight above 3 relative units). In this term the highest value of P.I. was found for the crop fertilized with 75 % share of sludge nitrogen. It was almost 3 relative units higher than in the control. In October (17.10) a similar tendency as during August were observed, the only exception was less intensive activity of photosynthetic apparatus, while the highest value of analyzed index was found for treatment „100% sludge".

An analysis of Performance Index PSII (P.I.) for lower layer of canopy leaves made 2.07 showed the use of sludge caused no visible effect (Fig. 2C). The highest value of Performance Index of Photosystem II was found for treatment without sludge nitrogen in applied rate of nitrogen. Data of measurements taken a month later (2.08) indicated significant effect of sludge used on the activity of photosynthetic apparatus of the crops. The highest value of analyzed P.I. was fund for the treatment 25% share of sludge nitrogen in the applied nitrogen rate. At the end of vegetation the activity of photosynthetic apparatus of Jerusalem artichoke upper layer of canopy leaves was low and the crop started to wilt, senesce and die The works of other authors imply the activity of photosynthetic apparatus of various plants, crops seems to be lower in autumn than in springtime or during the summer (KALAJI et al. 2004 a,b, KALAJI 2004).

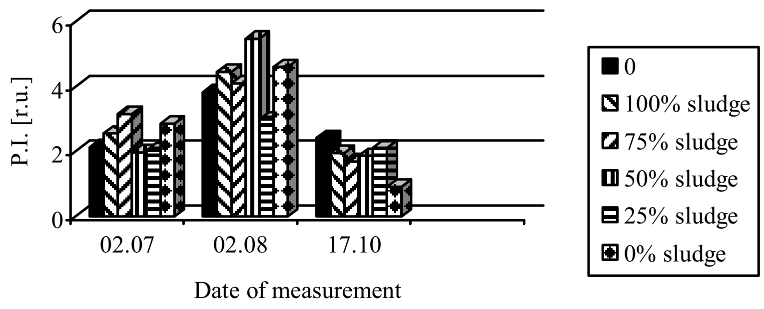

Fig. 2A. Changes of PSII Performance Index (P.I.) for Jerusalem artichoke upper layer of canopy leaves fertilized with a sludge during vegetation

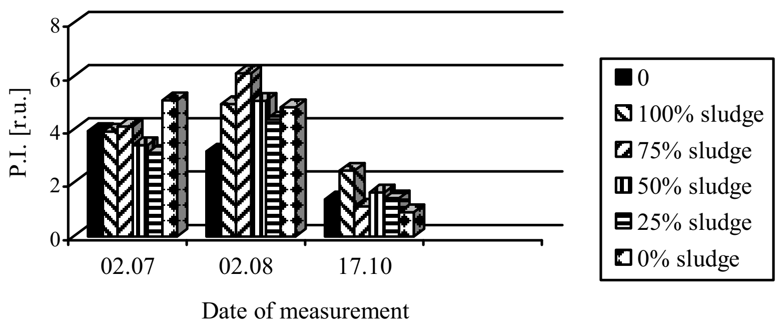

Fig. 2B. Changes of PSII Performance Index (P.I.) for Jerusalem artichoke central layer of canopy leaves fertilized with a sludge during vegetation

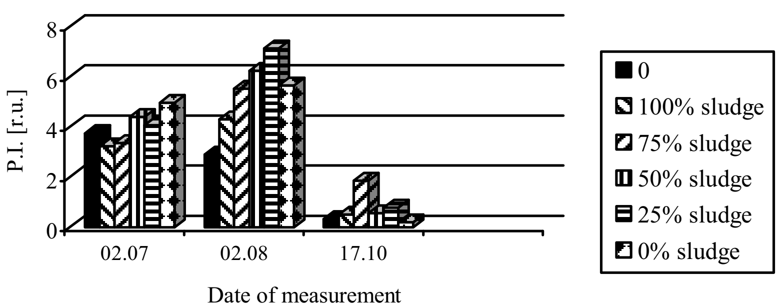

Fig. 2C. Changes of PSII Performance Index (P.I.) for Jerusalem artichoke upper layer of canopy leaves fertilized with a sludge during vegetation

Changes in maximum quantum yield of the Jerusalem artichoke Photosystem II

Numbered studied confirm the parameter F_V/F_M showed potential efficiency of PSII and can be used as a reliable indicator of photochemical activity of photosynthetic apparatus (KALAJI and ŁOBODA 2009). For a majority of plants in full development and under non stressed conditions its maximum value is 0,83 (ANGELINI et al. 2001). A decrease in the parameter shows an analyzed crop was earlier imposed to the activity of stress factors, which deteriorated functions of PS II, thus decreasing the efficiency of the electron transport (HE et al. 1996).

Figure 3 presents the changes of maximum quantum field of Photosystem II (F_V/F_M), for each individual date of measurement (global values), in Jerusalem artichoke fertilized with a sludge, for the whole vegetation period. The highest value of the analyzed index were noted in August (2.08), while the lowest ones by the end of vegetation. Noteworthy is that during the first months of vegetation no stimulating effect of a sludge on the analyzed index as compared to the applied sole mineral fertilizer was found. In October (17.10) the sludge, especially in treatment 75% sludge, affected considerably an increase in quantum field of Photosystem II.

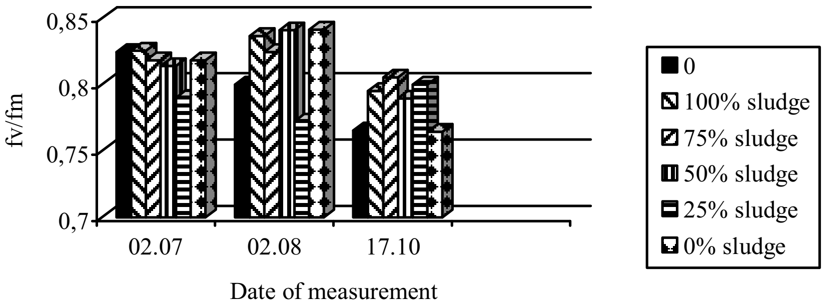

Fig. 3. Changes of PSII maximum quantum yield (F_V/F_M) for Jerusalem artichoke upper layer of canopy leaves fertilized with a sludge during vegetation

An analysis of changes in quantum yield of Photosystem II for upper layer of Jerusalem artichoke canopy leaves performed in July (2.07) showed the sludge only for treatments 100% sludge and 75% sludge stimulated increase in the analyzed index (Fig. 4A). A month later the highest values of F_V/F_M were obtained for the treatment with 50% sludge nitrogen in the applied rate of nitrogen, while a comparable for a treatment containing only mineral nitrogen. At the end of vegetation the higher values of maximum quantum yield than in the control were found only for treatment 75 % sludge. The lowest value were found for treatment with 100% share of mineral nitrogen in the applied rate of fertilizer.

Data obtained for July (2.07) in the respect of quantum yield of Photosystem II values for central layer of Jerusalem artichoke canopy leaves showed no significant differences for analyzed treatments (Fig. 4B). In August (2.08) significantly higher value of PSII quantum field were found for treatment involving a sludge only. At the end of vegetation (17.10) the higher values of the analyzed index were observed for treatment with a sludge than for that with mineral nitrogen.

Leaves of the Jerusalem artichoke lower layer canopy leaves showed no significant differences in quantum field of Photosystem II values, both in the view of date of measurement and treatment (Fig. 4C).

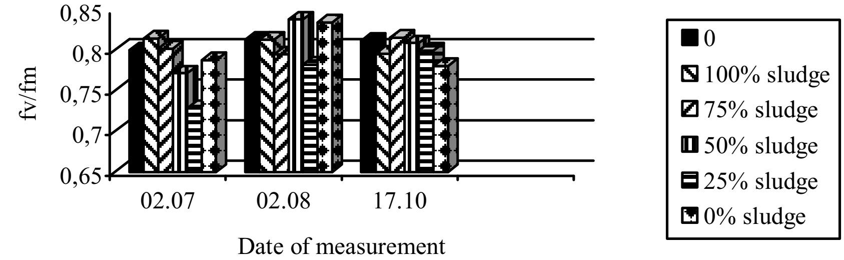

Fig. 4A. Changes of PSII maximum quantum yield (F_V/F_M) for Jerusalem artichoke upper layer of canopy leaves fertilized with a sludge during vegetation

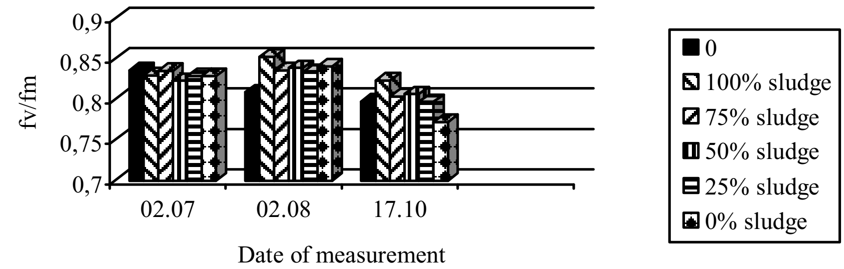

Fig. 4B. Changes of PSII maximum quantum yield (F_V/F_M) for Jerusalem artichoke central layer of canopy leaves fertilized with a sludge during vegetation

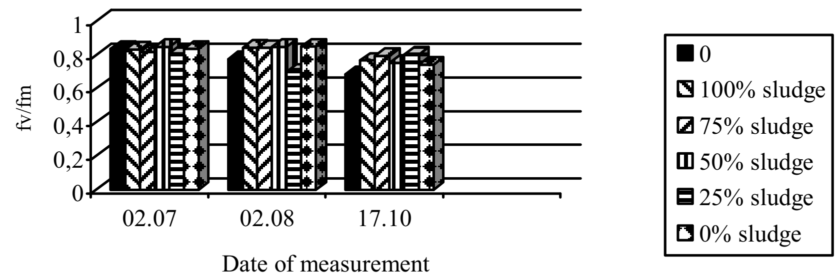

Fig. 4C. Changes of PSII maximum quantum yield (F_V/F_M) for Jerusalem artichoke lower layer of canopy leaves fertilized with a sludge during vegetation

Biomass yields of Jerusalem artichoke fertilized with a sludge is presented in table 3. It results from this data the highest biomass was found for the crop of the treatment, containing 100% share of sludge nitrogen in the applied nitrogen rate.

Jerusalem artichoke is a crop of high production potential. Cultivated in fertile soils and with the abundance of water topinambur can field to 200 $t \cdot ha^{-1}$ fresh weight (green above ground parts and tubers, together), with this tuber yield even 90 $t \cdot ha^{-1}$ (KOWALCZYK-JUŚKO 2003). On the other hand Kruczek (1995) reported tuber yield 15-30 $t \cdot ha^{-1}$ and green above ground mass: 50-70 $t \cdot ha^{-1}$. Comparison of these data with the ours resulted in finding the obtained biomass yield seems to be relatively low. However, the presented now data are from the first growing season after launching the plantation.

Table 3

Biomass field of Jerusalem artichoke fertilized with a sludge

Treatment	Biomass [$t \cdot ha^{-1}$]
0	21.94
100% sludge	33.89
75% sludge	31.87
50% sludge	30.08
25% sludge	25.25
0% sludge	28.50

Summary

Summing up, at the beginning of vegetation period an upper layer of Jerusalem artichoke (topinambur) canopy leaves of the treatment with 75% share of sludge nitrogen in applied nitrogen rate showed significantly higher Performance Index of Photosystem II. It was accompanied by higher maximum quantum field PSII for this layer, both for treatments 75% sludge and 100% sludge. In August there was an increase in activity of photosynthetic apparatus of the analyzed crops. This relationship especially strongly represent data obtained for the treatment with a sludge, where the values of P.I. were the highest for all studied layers of the canopy of the crops. At the end of vegetation period higher values both P.I. and maximum quantum yield of Photosystem II were observed both in crops fertilized with a sludge as compared to the treatments 0 and 0% sludge.

Differentiated nitrogen fertilization caused a diversification of processes in photosynthetic apparatus during Jerusalem artichoke vegetation. The rate 170 kg N $\cdot ha^{-1}$ based on 75% nitrogen provided by a sludge is an optimum rate for functioning of the photosynthetic apparatus, while the highest fresh mass field is provided when the nitrogen fertilization is completely based upon a sludge. Difference found for biomass yield for the above treatments was about 2 t fresh $weight \cdot ha^{-1}$.

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[1]Janusz Augustynowicz,
Department of Rural Sanitation
The of Land Reclamation and Grassland Farming
Falenty, Al. Hrabska 3, 05-090 Raszyn, POLAND

[2]Stefan Pietkiewicz, [2]Mohamed Hazem Kalaji
Department of Plant Physiology, Agriculture and Biology Faculty
Warsaw University of Life Sciences
ul. Nowoursynowska 159, 02-776 Warszawa, POLAND

[3]Stefan Russel
Free Standing of Microorganism Biology, Agriculture and Biology Faculty
Warsaw University of Life Sciences
ul. Nowoursynowska 159, 02-776 Warszawa, POLAND