**Full Length Article**

# Photosynthetic Efficiency in Sweet Potato (*Ipomoea batatas*) under Different Nitrogen Fertilization Regimes

**Barbara Krochmal-Marczak[1], Barbara Sawicka[2] and Władysław Michałek[3]**
[1]*State Higher Vocational School names Stanislawa Pigonia in Krosno, Department of Food Production and Safety, 38-400 Krosno, Poland*
[2]*University of Life Sciences, Department of Plant Production Technology and Commodity Sciences, 20-950, Lublin, Poland*
[3]*University of Life Science, Department of Plant Physiology, 20-950, Lublin, Poland*
[*]*For correspondence: barbara.marczak@pwsz.krosno.pl*

## Abstract

The photosynthetic activity of sweet potato leaves was determined under field experiment during 2015–2017 in Żyznów (49°49′ N, 21°50′ E), using split-plot design in three replicates. The experiment included doses of nitrogen (0, 50, 100, 150 kg N·ha⁻¹) and three sweet potato varieties (Beauregard, Carmen Rubin, and White Triumph). The aim was to establish the interactive effect on the physiological activity of sweet potato leaves ordered in the following way: environmental conditions > years x varieties > varieties > years x fertilisation > fertilisation x varieties > fertilisation > years x varieties x fertilisation. Genetic features of the studied varieties had a significant influence on physiological indicators, as: minimum fluorescence efficiency ($F_o$); maximum fluorescence efficiency ($F_m$); maximum photochemical efficiency of photosystem II ($F_v/F_m$) PSII efficiency on the light ($F_{v'}/F_{m'}$) and the actual photochemical efficiency of PSII (Y). Nitrogen fertilisation decreased in the maximum photochemical efficiency of PSII ($F_v/F_m$) which, affected the actual photochemical efficiency of PSII related to the electron transport efficiency (Y). The interaction of variety x fertilisation had the greatest influence on determining the minimum value of chlorophyll fluorescence, whereas the interaction of years x variety x fertilisation, had strong influence on the non-photochemical fluorescence quenching of chlorophyll (qN). © 2019 Friends Science Publishers

**Keywords:** Sweet potatoes; Chlorophyll fluorescence parameters; Nitrogen; Tuber yield, Varieties

## Introduction

Sweet potato (*Ipomoea batatas* L. [Lam.]) of *Convolvulaceae* family, is a popular root vegetable with tuberous roots, grown almost all over the world, from the tropical, to the subtropical and temperate climate (Woolfe, 1993). Sweet potato tubers and leaves are a valuable source of phenol antioxidants, in particular caffeic and chlorogenic acids (Kusano *et al.,* 2001; Everette *et al.,* 2012; Musilová *et al.,* 2017). Orange-flesh varieties are also rich in carotenoids (Teow *et al.,* 2007; Everette *et al.,* 2012; Mekonnen *et al.,* 2015; Aswathy *et al.,* 2017), whereas purple-flesh varieties are characterised by a high content of anthocyanins (Yang and Gadi, 2008; Krochmal-Marczak *et al.*, 2018). Nitrogen fertilisation aims to establish the optimal dose for a high-quality and yield that can be established taking into account the physiological reactions of plants especially whenever new varieties are cultivated, whose reactions may be unusual. The physiological processes in the plant may be characterised by high variability depending on the genotype, habitat and nitrogen fertilisation. Nitrogen plays a fundamental role in the production of plant biomass. Approximately 20–50% of nitrogen in leaves is a part of

protein. Increased nitrogen supply also contributes to leaf longevity and has a huge impact on biomass growth and crop yield. Nitrogen deficiency significantly hinders photosynthesis affecting gene expression (Živčák *et al.*, 2014a, b; Koning *et al.,* 2015). In extreme cases, disintegration of chloroplasts manifests itself in the disintegration of thylakoids and the appearance of plastoglobules (Kalaji *et al.,* 2004). Chlorophyll fluorescence is expressed in relative units. Gradual fluorescence quenching is related to the increase of $CO_2$ assimilation at the stage of biochemical photosynthesis (Sawicka *et al.,* 2018). According to Cortivo *et al.* (2017), adjusting the nitrogen dose may not be sufficient. Therefore, the aim of this research was to determine the influence of nitrogen fertilisation on the physiological activity of leaves and establish the optimal nitrogen doses in relation to the physiological indicators of sweet potato.

## Materials and Methods

### Experimental Details and Treatments

The photosynthetic activity of sweet potato leaves was

based on a field experiment from 2015–2017 in Żyznów (49°49′ N, 21°50′ E), using the random sub-blocks method, in a dependence system, split-plot design, in three replicates.

**Treatments**

The main experimental factor included were doses of nitrogen (0, 50, 100, 150 kg N·ha⁻¹) and varieties as the secondary factor (Beauregard, Carmen Rubin and White Triumph). Nitrogen fertilisation was used simultaneously to NPK fertilisation in the following amounts: 80 kg N; 34.9 kg P; 99.6 kg K·ha⁻¹ and 25 t·ha⁻¹ of manure. Manure fertilisation was used in the autumn, whereas mineral fertilisation – in the spring, prior to planting. The propagating material included rooted cuttings of sweet potato from *in vitro* propagation. They were planted with 40 x 75 cm spacing in mid-May. The size of crop plots was 15 m². During vegetation, cultivation was carried out in accordance with normal agricultural practice. In the vegetation period, the photosynthetic activity was determined right before flowering (BBCH stage 59), at the third leaf stage of sweet potato, with the use of the PAM-2000 fluorometer from Walz GmbH. The physiological indicators measured at that stage of development were justified, because the changes occurring in physiological processes at that time have a significant influence on future photosynthetic efficiency, as plants have already absorbed most of the supplied nitrogen (Anonymous, 2018). The physiological indicators were measured with the use of the 2030-B leaf-clip, a 650-nm light source and standard flow rate of 0.15 m⁻²s⁻¹ of PAR. During the measurement, at the dark adaptation stage, leaves were dark-adapted for 20 minutes with the use of special clips from Walz GmbH. The following fluorescence parameters were determined: minimum efficiency of chlorophyll fluorescence ($F_o$), maximum efficiency of chlorophyll fluorescence ($F_m$); maximum PSII efficiency in the dark ($F_v/F_m$); PSII efficiency in the light ($F_{v'}/F_{m'}$); current number of electrons in the light-adapted PSII–ΦPSII; photochemical (qP) and non-photochemical (qN) fluorescence quenching coefficients. The measurement of physiological indicators was carried out on leaves at the same location on the plant and with similar orientation to the light. Minimum chlorophyll efficiency ($F_o$) and maximum efficiency of chlorophyll fluorescence ($F_m$) were measured at weak modulated red light (<0.5 $\mu$mol m⁻² s⁻¹) with 1.6-s pulses of saturating light (> 6.8 $\mu$mol m⁻² s⁻¹ of PAR) and calculated with the FMS software for Windows. The efficiency of chlorophyll fluorescence ($F_v$) was calculated with the use of the following formula: $F_v = F_m - F_o$. The variable to maximum fluorescence ratio ($F_v/F_m$) was calculated as the maximum quantum efficiency in the centre of PSII, *i.e.*, maximum photochemical efficiency of photosystem II.

**Statistical Analysis**

The results were analysed statistically by means of the analysis of variance (ANOVA). The significance of the sources of variance was examined in F-Snedecor test and the significant differences between the compared means were evaluated in Tukey's honest significant difference test. In order to establish the influence of individual sources of variance and their interactions on the total variance of the examined parameters, estimation of variance components was carried out, where: $\delta e^2$ – is the estimate of environmental variance related to repeated observations or measurements in a specific time; $\delta N^2$–is the estimate of fertilisation variance; $\delta p^2$ – is the estimate of (total) phenotypic variance. The empirical results of mean squares were compared to the expected values. The variance components of individual sources of variance were estimated and their percentage distribution was established. The interrelations of the estimates of variance components and their percentage distribution were the basis for estimating the influence of varieties, fertilisation, and years on the variance of the examined parameters. Coefficients of variability of the examined parameters were also calculated as the indicator of the dispersion of results (Zimny, 2010).

**Weather Conditions**

The humidity and temperature conditions during sweet potato vegetation were described with the use of the hydrothermal coefficient of Selyaninov (Table 1).
The crop growing 2016–2017 were wet with 2015 extremely humid and reflected in the values of the hydrothermal coefficient of Selyaninov (Table 1). However, significant variation of the hydrothermal coefficient was observed between individual months of the vegetation period. In 2015, all vegetation months were wet, with an extremely humid July and a dry September. In 2016, almost all months, except for a dry October, were wet or very wet. In 2017, July and September were extremely dry, with a dry October, whereas all the other months were wet or very wet, with an extremely humid June. This data enables the interpretation of the physiological condition and the photosynthetic efficiency of plants (Skowera, 2014).

**Soil Physico-chemical Characteristics**

The concentration of assimilable phosphorus, potassium, copper, iron, and zinc in soil was on a medium level, with a very high content of magnesium. The average content of humus in the topsoil was 2.66%, with a slight acidity of soil (Table 2).

**Results**

The photosynthetic efficiency of sweet potato leaves was significantly influenced by the genetic properties of the varieties, fertilisation and environmental conditions (Table 3–6). The factor determining the variation of physiological indicators of sweet potato were mostly the environmental

**Table 1:** Hydrothermal coefficient of Selyaninov during the sweet potato vegetation period in 2015–2017 according to the COBORU meteorological station in Dukla

| Month | 2015 | 2016 | 2017 | Mean |
|---|---|---|---|---|
| May | 3.3 | 2.8 | 2.6 | 2.9 |
| June | 1.9 | 2.9 | 4.9 | 3.2 |
| July | 6.1 | 1.3 | 0.2 | 2.5 |
| August | 2.5 | 2.9 | 2.1 | 2.5 |
| September | 0.9 | 2.0 | 0.3 | 1.1 |
| October | 2.3 | 0.3 | 0.8 | 1.1 |
| Mean | 2.8 | 2.0 | 1.8 | 2.2 |

Source: own study according to data from the COBORU meteorological station at SDOO in Dukla. The following ranges of values for the coefficient of Selyaninov were assumed: extremely dry $k \leq 0.4$; very dry $0.4 < k \leq 0.7$; dry $0.7 < k \leq 1.0$; quite dry $1.0 < k \leq 1.3$; optimal $1.3 < k \leq 1.6$; quite damp $1.6 < k \leq 2.0$; wet $2.0 < k \leq 2.5$; very wet $2.5 < k \leq 3.0$; extremely humid $k > 3.0$

**Table 2:** The content of available forms of macro- and micronutrients, content of humus and soil pH

| Years | Macronutrients (mg$\cdot$100g$^{-1}$ of soil) | | | CaCO$_3$ (%) | Humus (%) | pH (KCL) | Micronutrients (mg$\cdot$100 g$^{-1}$ of soil) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | P$_2$0$_5$ | K$_2$0 | Mg | | | | Cu | Mn | Zn | Fe |
| 2015 | 12.5 | 20.1 | 19.6 | 0.02 | 2.70 | 5.55 | 5.60 | 173 | 14.8 | 1591 |
| 2016 | 12.3 | 20.0 | 19.7 | 0.03 | 2.73 | 5.73 | 5.70 | 172 | 14.5 | 1573 |
| 2017 | 12.4 | 20.0 | 19.5 | 0.02 | 2.69 | 5.70 | 5.60 | 176 | 14.6 | 1572 |
| Mean | 12.4 | 20.0 | 19.6 | 0.02 | 2.71 | 5.66 | 5.63 | 174 | 14.6 | 1578 |

Source: data was compiled on the basis of the results obtained by the District Chemical and Agricultural Station in Krosno in 2015–2017

**Table 3:** Effect of fertilisation and year on some parameters of chlorophyll fluorescence in leaves of *Ipomoea batatas* and the percentage of variance in total variance

| Specification | Percentage of variance in total variance | | | | | | | Significance of effect | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | years | variety | fertilisation | years x variety | years x fertilisation | fertilisation x variety | years x variety x fertilisation | years | variety | fertilisation | years x variety | years x fertilisation | fertilisation x variety | years x variety x locality |
| F$_o$ | 54.5 | 13.6 | 1.1 | 4.4 | 13.7 | 9.1 | 3.2 | ** | ** | ns | ns | ** | ** | Ns |
| F$_m$ | 36.7 | 17.7 | 2.1 | 15.7 | 11.5 | 8.8 | 7.3 | ** | ** | ns | ** | ** | * | * |
| F$_v$/F$_m$ | 29.6 | 9.2 | 15.2 | 29.0 | 9.9 | 7.1 | 1.1 | ** | ** | ** | ** | ** | * | Ns |
| F$_{v'}$/F$_{m'}$ | 51.7 | 12.3 | 0.5 | 14.8 | 12.3 | 1.2 | 8.1 | ** | ** | ns | ns | ** | ns | * |
| Y | 54.2 | 6.4 | 7.1 | 14.2 | 9.2 | 4.1 | 6.1 | ** | ** | ** | ** | ** | ns | * |
| qP | 55.1 | 0.9 | 2.2 | 22.7 | 11.4 | 6.8 | 2.0 | ** | ns | ns | ** | * | ** | Ns |
| qN | 18.5 | 29.5 | 5.8 | 31.5 | 1.1 | 3.5 | 12.1 | ** | ns | * | ** | ns | ns | * |
| V | 35.4 | 12.9 | 5.6 | 21.1 | 12.1 | 8.8 | 4.9 | | | | | | | |

qP – photochemical fluorescence quenching coefficient; qN – non-photochemical fluorescence quenching coefficient; F$_o$ – minimum fluorescence efficiency; F$_m$ – maximum fluorescence efficiency; F$_v$/F$_m$ – maximum photochemical efficiency of photosystem II; F$_{v'}$/F$_{m'}$ – PSII efficiency on the light; Y – the actual photochemical efficiency of PSII; * significant at P$_{0.05}$, ** significant at P$_{0.01}$, *** not significant at p$_{0.05}$

conditions in the research years (18.5–55.1%) (Table 3). The smallest influence of the environment on the phenotypic variance was observed in non-photochemical fluorescence quenching of chlorophyll and the largest – on photochemical fluorescence quenching of chlorophyll. The influence of varieties on the total phenotypic variance fluctuated from 0.9 to 29.5%, with the highest value for non-photochemical fluorescence quenching of chlorophyll. The fertilisation factor had the least influence on determining the physiological indicators of chlorophyll fluorescence, with its value fluctuating from 0.5% in the case of PSII effectiveness in the light, to 15.2% in the case of maximum PSII effectiveness in the dark. The influence of the years x fertilisation interaction on determining the physiological indicators fluctuated between 1.1% in the case of non-photochemical fluorescence quenching and 13.7% in the case of minimum effectiveness of chlorophyll fluorescence. The interaction of variety x fertilisation had the greatest influence on determining the minimum value of chlorophyll fluorescence, whereas in the triple interaction of years x variety x fertilisation, the most influential was the

non-photochemical fluorescence quenching of chlorophyll. The coefficient of variation, independent from the unit scale, showed the greatest stability for the years x varieties x fertilisation interaction and the greatest variation in the case of years (Table 3).

Genetic features of the examined varieties had a significant influence on the value of most of the physiological indicators, except: minimum fluorescence of chlorophyll and the coefficients of photochemical and non-photochemical fluorescence quenching of chlorophyll (Table 4). The minimum effectiveness of fluorescence (F$_o$), *i.e.*, the effectiveness of fluorescence following dark adaptation, was on average 0.223. The highest value of this parameter was observed in the Beauregard variety, and the lowest in Carmen Rubin. This characteristic turned out to be the same in the Beauregard and the White Triumph varieties (Table 4).

The highest maximum efficiency of PSII in the dark was observed in the Carmen Rubin variety, whereas the lowest – in White Triumph. This characteristic turned out to be homogeneous for the Beauregard and the White Triumph

**Table 4:** The influence of varietal traits on selected chlorophyll fluorescence parameters. Mean for 2015–2017*

| Varieties | $F_o$ | $F_m$ | $F_v/F_m$ | $F_{v'}/F_{m'}$ | Y | qP | qN |
|---|---|---|---|---|---|---|---|
| Beauregard | 0.238 | 1.043 | 0.606 | 0.388 | 0.464 | 0.599 | 0.162 |
| Carmen Rubin | 0.197 | 0.998 | 0.658 | 0.536 | 0.433 | 0.579 | 0.164 |
| White Triumph | 0.235 | 1.034 | 0.611 | 0.414 | 0.459 | 0.601 | 0.167 |
| Mean | 0.223 | 1.025 | 0.625 | 0.445 | 0.452 | 0.593 | 0.164 |
| $HSD_{0.05}$* | 0.011 | ns** | 0.032 | 0.023 | 0.023 | ns | ns |

*Explanations as in Table 3

**Table 5:** Effect of nitrogen fertilisation on means values of chlorophyll fluorescence traits for both years (2015–2017)

| Fertilisation [kg·ha⁻¹] | $F_o$ | $F_m$ | $F_v/F_m$ | $F_{v'}/F_{m'}$ | Y | qP | qN |
|---|---|---|---|---|---|---|---|
| 0 | 0.202 | 1.044 | 0.647 | 0.417 | 0.442 | 0.614 | 0.138 |
| 50 | 0.248 | 1.135 | 0.702 | 0.476 | 0.519 | 0.658 | 0.193 |
| 100 | 0.254 | 1.098 | 0.693 | 0.450 | 0.503 | 0.652 | 0.195 |
| 150 | 0.252 | 1.113 | 0.635 | 0.421 | 0.469 | 0.615 | 0.176 |
| Mean | 0.239 | 1.098 | 0.669 | 0.441 | 0.484 | 0.635 | 0.176 |
| $HSD_{0.05}$ | 0.015 | 0.070 | 0.043 | 0.022 | 0.031 | 0.030 | 0.011 |

**Table 6:** Effect of years on selected chlorophyll fluorescence indices

| Years | $F_o$ | $F_m$ | $F_v/F_m$ | $F_{v'}/F_{m'}$ | Y | qP | qN |
|---|---|---|---|---|---|---|---|
| 2015 | 0.240 | 1.134 | 0.704 | 0.445 | 0.450 | 0.644 | 0.181 |
| 2016 | 0.191 | 0.844 | 0.502 | 0.429 | 0.421 | 0.500 | 0.136 |
| 2017 | 0.239 | 1.098 | 0.669 | 0.440 | 0.484 | 0.635 | 0.176 |
| Mean | 0.223 | 1.025 | 0.625 | 0.438 | 0.451 | 0.593 | 0.164 |
| $HSD_{0.05}$ | 0.011 | 0.052 | 0.032 | ns* | 0.023 | 0.030 | 0.008 |

Explanations as in Table 4

varieties. However, Beauregard demonstrated the highest value of the minimum chlorophyll fluorescence and the actual photochemical efficiency of PSII, whereas Carmen Rubin – the greatest efficiency of PSII in the light (Table 4).

Nitrogen fertilisation had a significant influence on individual parameters of chlorophyll fluorescence of sweet potato leaves. The greatest efficiency of PSII in the light was observed in the control group with no nitrogen fertilisation. For the majority of chlorophyll fluorescence parameters, the most advantageous was the fertilisation dose of 50 kg N ha⁻¹, and following a further increase of such fertilisation, the values started to drop. Changes also occurred in the actual photochemical efficiency of PSII related to the electron transport efficiency (Y). Based on this parameter, the ratio of quanta used in the photochemical reactions to the total number of absorbed PAR quanta was calculated. As nitrogen fertilisation increased, the electron transport efficiency (Y) reached a significantly lower value (Table 4).

In order to determine the optimal dose of nitrogen for individual parameters of chlorophyll fluorescence, polynomial regression analysis was applied (Fig. 1).

Under the influence of increasing nitrogen fertilisation, the following parameters: Fo, Fm, $F_v/F_m$ and $F_{v'}/F_{m'}$ formed a second- or third-order regression line. The optimal nitrogen dose for the maximum efficiency of chlorophyll fluorescence was 40 kg N ha⁻¹, the optimal nitrogen dose for the minimum efficiency of chlorophyll fluorescence was 83 kg N ha⁻¹, and for the maximum efficiency of PSII in the
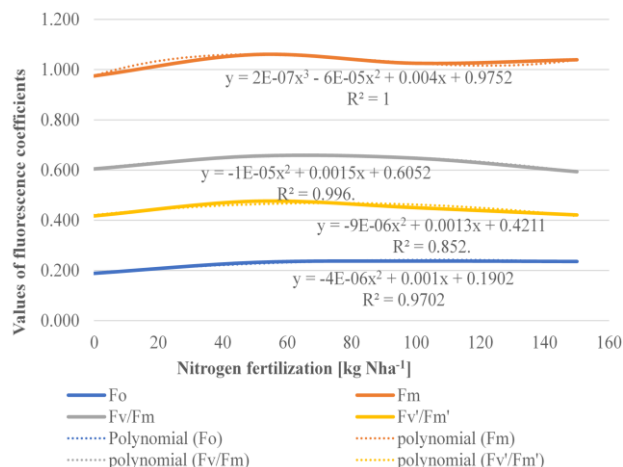


**Fig. 1:** Values of partial regression coefficients of chlorophyll fluorescence parameters depending on nitrogen fertilization of sweet potato
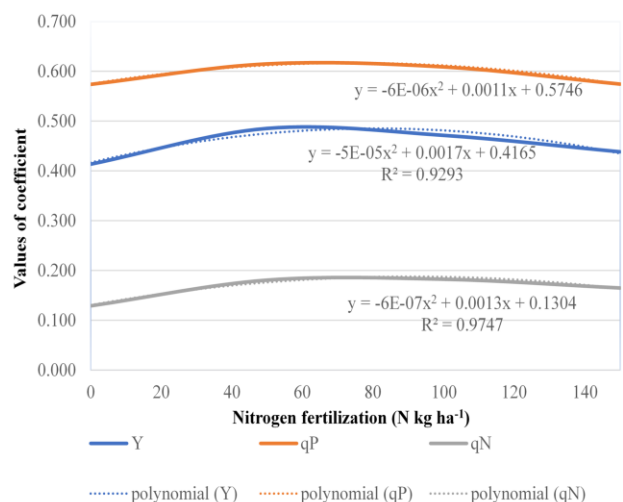


**Fig. 2:** Partial regression values of actual photochemical PSII (Y) efficiency, photochemical quenching coefficient (qP) and non-photochemical quenching coefficient (qN) depending on nitrogen fertilisation

dark was–41 kg N·ha⁻¹ (Fig. 1).

The analysis of polynomial regression for the photochemical efficiency of PSII (Y), the photochemical quenching of fluorescence (qP) and the non-photochemical quenching of fluorescence (qN) showed a second-order parabolic dependence from nitrogen fertilisation. The optimal nitrogen dose for the photochemical efficiency of PSII (Y) was 91.7 kg N·ha⁻¹, for the non-photochemical quenching of fluorescence (qP)–92.9 kg N·ha⁻¹ and for the photochemical quenching of fluorescence (qP), it amounted to 17 kg N·ha⁻¹ (Fig. 2).

The values of individual parameters related to chlorophyll fluorescence were significantly influenced by the weather conditions during growing period (Table 6).

Almost all physiological indicators of leaf activity, except for the PSII efficiency in the light, demonstrated a significant dependence during both years. The indicators reached peak values in the wet yet warm year 2015 and the lowest values in the wet and cold year 2016.

## Discussion

The measurement of chlorophyll fluorescence induction is one of the ways the photosynthetic mechanism of plants works, in particular photosystems (Brestic and Zivak, 2013). The excitation of chlorophyll particles can only be quenched by means of a photochemical reaction, heat generation and the alternative fluorescence process. If the photochemical processes are reduced, the efficiency of fluorescence usually improves. Nitrogen fertilisation, the genetic characteristics of the examined varieties, and the weather conditions differentiated the sweet potato photosynthetic efficiency. According to Kalaji *et al.* (2004), Adamski *et al.* (2012), Sawicka *et al.* (2018), Szymanski *et al.* (2018) and every variety produces assimilates in an individual way, which is reflected by differences in chlorophyll fluorescence as during present study. Koning *et al.* (2015) and Sawicka *et al.* (2018) reported that chlorophyll fluorescence is the indicator of the efficiency of the photosynthetic mechanism that depend on genotypic features and the nitrogen fertilisation dose. The efficiency of photosynthesis is the highest if the leaf blade surface is a minimum size, and it decreases as the leaf blade grows. According to Yooyongwech *et al.* (2017) the Japanese Yellow variety, with water deficit tolerance, is a positive example of the use of chlorophyll fluorescence parameters in the evaluation of varieties' tolerance to water stress.

The minimum efficiency of chlorophyll fluorescence ($F_o$) was 0.223. All PSII reaction centres are open, and the electron pool is completely oxidised is the indicator of energy absorption by chlorophyll particles functionally unrelated to the reaction centres (Yooyongwech *et al.*, 2017). The maximum efficiency of chlorophyll fluorescence of a leaf in the light, induced by the saturating light impulse ($F_m$), is related to the maximum efficiency of PSII following dark adaptation (Augustynowicz *et al.*, 2009, 2010; Adamski *et al.*, 2011).

In south-eastern Poland, the average $F_v/F_m$ value was 0.625. For the proper system functioning, the $F_v/F_m$ value usually ranges from 0.67–0.83 and in the case of sweet potato grown in south-eastern Poland, the value was slightly lower, but still within the bottom limit of the fluorescence. The potential quantum efficiency ($F_v/F_m$) was the highest in the Carmen Rubin variety, and the lowest in the Beauregard variety. It must be also noted that the value decrease showed a decreased demand of plants for the products the so-called assimilation capacity, and the interference in the development process of the examined plants. And increased nitrogen dose caused a decrease in the maximum quantum efficiency of PSII (the $F_v/F_m$ parameter). This probably influenced a similar decrease of over ten percent in the total quantum efficiency of the process of energy conversion in PSII (the Y parameter). A small decrease of the photochemical fluorescence quenching coefficient (qP) is a result of a slightly retarded primary oxidation and quinone electron acceptor ($Q_A$) in the PSII by plastoquinone. The decreased value of non-photochemical quenching, with a dose of 100 kg N ha$^{-1}$, indicates that in such conditions, the sweet potato plants experienced the most interference, which is most probably related to the reduced use of ATP at the dark stage of photosynthesis as a result of increased fertilisation with this ingredient. After all, nitrogen is first absorbed by the roots and shoots, and then transported to the leaves. Yooyongwech *et al.* (2017) proved that 32.3% soil water content (SWC), as compared to untreated plants, adjusts the osmotic potential of leaves and controls the closing of stomata. Moreover, free proline content can increase almost 4-fold with greater exposure to soil water. It was also pointed out to the positive relation between PSII photon yield (Φ PSII) and the net photosynthesis rate (r=0.73).

## Conclusion

The factors determining the physiological indicator variation of sweet potato leaves can be ordered in the following way: environmental conditions > years × varieties > varieties > years × fertilisation > fertilisation × varieties > fertilisation > years × varieties x fertilisation. The genetic characteristics of the examined varieties had a significant influence on the value of the plants' physiological indicators. The Beauregard variety demonstrated the highest value of the minimum chlorophyll fluorescence and the actual photochemical efficiency of PSII, whereas Carmen Rubin – the greatest efficiency of PSII in the light. The optimal nitrogen dose for the value of the Y indicator was 91.7 kg N ha$^{-1}$, for the non-photochemical quenching of fluorescence (qN), it was 92.9 kg N ha$^{-1}$ and for the photochemical quenching of fluorescence (qP) – 17 kg N ha$^{-1}$. The chlorophyll fluorescence parameters were highly dependent on the conditions during cropping year. The traits reached the highest values in wet yet warm years and the lowest in wet and cold years, unfavourable to photosynthesis. The interaction of variety x fertilisation had the greatest influence on determining the minimum value of chlorophyll fluorescence, whereas the interaction of years x variety x fertilisation, had strong influence on the non-photochemical fluorescence quenching of chlorophyll (qN).

## References

Adamski, J.M., R. Danieloski, S. Deuner, E.J.B. Braga, L.A.S. Castro and J.A. Peters, 2012. Responses to excess iron in sweet potato: impacts on growth, enzyme activities, mineral concentrations and anatomy. *Acta Physiol. Plantarum,* 34: 1827–1836

Adamski, J.M., J.A. Peters, R. Danieloski and M.A. Bacarin, 2011. Excess iron-induced changes in the photosynthetic characteristics of sweet potato. *J. Plant Physiol.,* 168: 2056–2062

Anonymous, 2018. *Phenological growth stages and BBCH-identification keys of potato (Solanum tuberosum L.) Scale BBCH (potato).* Available at: https://en.wikipedia.org/wiki/BBCH-scale_(potato) (Accessed: 23 December 2018)

Aswathy, G.H., P. Nair, V. Vidya, J. Ambu, C. Sreekumar and C. Mohan, 2017. Evaluation of orange fleshed sweet potato genotypes for storage root yield and dry matter content. *Intl. J. Appl. Pure Sci. Agric.,* 3: 82–85

Augustynowicz, J., S. Pietkiewicz, M.H. Kalaji and S. Russel, 2010. Influence of sewage sludge fertilization on selected parameters of soil biological activity and efficiency of photosynthetic apparatus of Jerusalem artichoke (*Helianthus tuberosus* L.). *Water-Environ. Rural Areas,* 2: 7–18

Augustynowicz, J., S. Pietkiewicz, M.H. Kalaji and S. Russel, 2009. The effect of sludge fertilization on choosen parameters of chlorophyll fluorescence and biomass yield of Jerusalem artichoke (*Helianthus tuberosus* L.). *In*: *Sewages and Waste Materials in Environment*, pp: 129–139. Sądej, M.W. (Ed.). Department of Land Reclamation and Environmental Management, University of Warmia and Mazury in Olsztyn, Poland

Brestic, M. and M. Zivcak, 2013. PSII fluorescence techniques for measurement of drought and high temperature stress signal in plants: protocols and applications. *In: Molecular Stress and Physiology of Plants,* pp: 87–96. Rout, G.R. and A.B. Das (Eds.). Springer, The Netherlands

Cortivo, C.D., G. Barion, G. Visioli, M. Mattarozzi, G. Mosca and T. Vamerali, 2017. Increased root growth and nitrogen accumulation in common wheat following PGPR inoculation: Assessment of plant-microbe interactions by ESEM. *Agric. Ecosyst. Environ.,* 247: 396–408

Everette, J.D., A. Zelalema, R.B. Walker and S. Islam, 2012. Antioxidant activity and phenolic content of orange-fleshed sweet potatoes. *Ark. Environ. Agric. Consum. Sci. J.,* 2012: 34–38

Kalaji, M.H., K. Rykaczewska, S. Pietkiewicz and E. Kotlarska-Jaros, 2004. Influence of foliar sulfur-nitrogen fertilization on the activity and development of potato plants by chlorophyll fluorescence a. *Adv. Appl. Agric. Sci.,* 496: 367–374

Koning, L.A., M. Veste, D. Frees and S. Lebzien, 2015. Effects of nitrogen and phosphate fertilization on leaf nutrient content, photosynthesis, and growth of the novel bioenergy crop *Fallopia sachalinensis* cv. 'Igniscum Candy'. *J. Appl. Bot. Food Qual.,* 88: 22–28

Krochmal-Marczak, B., S. Sawicka and R. Tobiasz-Salach, 2018. Impact of cultivations technology on the yield of sweet potato (*Ipomoea Batatas* L) tubers. *Emir. J. Food Agric.,* 30: 978–983

Kusano, S., H. Abe and H. Tamura, 2001. Isolation of antidiabetic components from white-skinned sweet potato (*Ipomoea batatas* L.). *Biosci. Biotechnol. Biochem.,* 65: 109–114

Mekonnen, B., S. Tulu and J. Nego, 2015. Orange fleshed sweet potato (*Ipomoea batatas* L.) varieties evaluated with respect to growth parameters at Jimma in Southwestern Ethiopia. *J. Agron.,* 14: 164–169

Musilová, J., J. Bystrická, J. Árvay and L. Harangózo, 2017. Polyphenols and phenolic acids in sweet potato (*Ipomoea batatas* L.) roots. *Potravin. Slov. J. Food Sci.*, 11: 82–87

Sawicka, B., W. Michałek, P. Pszczółkowski and H. Danilčenko, 2018. Variation in productivity of sweet potato (*Ipomoea batatas* L. [Lam.]) under different conditions of nitrogen fertilization. *Zemdirbyste-Agriculture,* 105: 149–158

Skowera, B., 2014. Changes in hydrothermal conditions in Poland. (1971−2010). *Fragm. Agron.,* 31: 74–87

Szymanski, N., I. Burzyńska, H.M. Kalaji and G. Mastalerczuk, 2018. Fluorescence of chlorophyll as a tool to assess the degree of eutrophication of aquatic ecosystems on the example of ponds in the area of Raszyn commune. *Ecol. Eng.,* 19: 73–80

Teow, C.C., T. Van-Den, R.F. McFeeters, R.L. Thompson, K.V. Pecota and G.C. Yencho, 2007. Antioxidant activities, phenolic and β-caratene contents of sweet potato genotypes with varying flesh colours. *Food Chem.,* 103: 829–838

Woolfe, J., 1993. *Sweet Potato: An Untapped Food Resource*. Cambridge University Press, Cambridge, UK

Yang, J. and R.L. Gadi, 2008. Effects of steaming and dehydration on anthocyanins, antioxidant activity, total phenols and color characteristics of purple-fleshed sweet potatoes (*Ipomoea batatas*). *Amer. J. Food Technol.,* 3: 224–234

Yooyongwech, S., T. Samphumphuang, R. Tisarum, C. Theerawitaya and S. Cha-um, 2017. Water-deficit tolerance for water deficiency in sweet potatoes (*Ipomoea batatas* [L.] Lam.) By foliar application of paclobutrazol: the role of soluble sugar and free proline. *Front. Plant Sci.,* 8: 1–13

Živčák, M., M. Brestic, H.M. Kalaji and Govidendjee, 2014a. Photosynthetic responses of sun- and shade-grown barley leaves to high light: is very lover PSII connectivity in shade leaves associated with protection against excess of light? *Photosynth. Res.,* 119: 339–354

Živčák, M., K. Olšovská, P. Slamka, J. Galambošová and V. Rataj, 2014b. Application of chlorophyll fluorescence performance indices to assess the wheat photosynthetic functions influenced by nitrogen deficiency. *Plant Soil Environ.,* 60: 210–215

Zimny, A., 2010. *Descriptive statistics*. Publisher of the State Higher Vocational School in Konin,