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HARVEST INDEX OF POTATO CROP GROWN UNDER DIFFERENT NITROGEN AND WATER SUPPLY*

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Abstract. On the basis of the field experiment carried out at the Experimental Station at Jadwisin (52°29' N; 21°03' E), Polish mid-early potato cultivar Triada was grown on sandy loam in years 2004 and 2005 in 6 treatments, which included the application of water and nitrogen: organic (cattle manure) and mineral. Water drip irrigation and nitrogen fertigation were scheduled by the Decision Support System (DSS). Diverse water supplies and organic or mineral nitrogen did not change harvest index (HI) values, which varied between 0.7 and 0.8 at the end of the growing period. Average tuber dry matter yield, about 11.0 $t \cdot ha^{-1}$, in both years of the investigation was reached with different HI values: 0.78 for 2004, and 0.73 for 2005. Higher percentage of biomass distributed to tubers was found in 2004, which was characterized by lower cumulative thermal time and global radiation, as well as better water balance in comparison with the growing period of 2005.

Key words: drip irrigation, harvest index, nitrogen fertigation, organic and mineral nitrogen, potato crop

INTRODUCTION

Every kind of biomass produced by plants is equally important for ecosystem functioning, since the chemical energy of organic compounds, which form biomass, is a form of permanent storing of solar energy on Earth.

In agriculture, of particular importance is the part of cultivated plants biomass called agricultural crop, which is used for feeding people and animals. Parameter that characterises the participation of agricultural crop in the total plant biomass is harvest index (HI). In potato plants, the value of this parameter depends mostly on the genetic traits of the cultivar and the conditions of the environment, such as: photoperiod, air

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temperature, solar radiation, supply with water, and nitrogen fertilisation [Jefferies and MacKerron 1989, Gawrońska et al. 1990, Ewing and Sandlan 1995, Vos 1997, Mazurczyk and Lis 2000, Belanger et al. 2001].

The aim of the work was the characterisation of the effect of diversified potato plant supply with nitrogen and water on biomass distribution between tubers (agricultural crop) and the remaining organs.

MATERIAL AND METHODS

Study material originated form the field experiment carried out on the Plant Breeding and Acclimatisation Institute experimental plot at Jadwisin (52^{o}29' N; 21^{o}03' E), as a randomized complete block design, each object in three replications. Experiment was carried out in years 2004-2005. Plot size was 70 m^2. Mid-early cultivar Triada was grown with spacing 75 x 33.3 cm, which means that on every plot, there were 280 plants. Experiment was set on light sandy loam. Studied treatments are shown in Table 1.

Table 1. Schema of the field experiment carried out at the Experimental Station at Jadwisin, 2004-2005
Tabela 1. Schemat doświadczenia polowego przeprowadzonego w IHAR Jadwisin, 2004-2005

Fertilisation and irrigation Nawożenie i nawadnianie	Treatment – Kombinacja					
	A	B	C	D	E	F
Cattle manure – Obornik	0	+	0	+	+	+
Fertigation N_{min} – Fertygacja $N_{min.}$	0	0	0	0	+*	+**
Irrigation – Nawadnianie	0	0	+	+	+	+

0 – no tested factor – brak danego czynnika
+ – tested factor was applied – zastosowany czynnik
* static option of DSS: set of supplementary N doses and application dates were established basing on the nitrogen balance at the beginning of the growing period – statyczna fertygacja: komplet uzupełniających dawek azotu i terminy ich aplikacji wyznaczane były w oparciu o bilans azotu dla początku okresu wegetacji
** dynamic option of DSS: N doses and application dates were determined during the growing period – dynamiczna fertygacja: dawki N oraz terminy ich stosowania wyznaczane były na bieżąco w trakcie trwania wegetacji

Cattle manure was applied in the spring, in doses calculated with the assumption that they should cover 50% of the total potato plant need for nitrogen. The doses amounted to 33.3 t·ha^{-1} (145 kg·ha^{-1} N) in 2004 and 20.8 t·ha^{-1} (58 kg·ha^{-1} N) in 2005 (Table 2).

Table 2. Amounts of nitrogen [kg·ha^{-1}] and water [mm] applied in the years of the experiment
Tabela 2. Ilości azotu [kg·ha^{-1}] oraz wody [mm] zastosowane w latach badań

Specification – Wyszczególnienie	Year – Rok	
	2004	2005
Cattle manure – Obornik	145.0	58.0
Static fertigation – Fertygacja statyczna (E)	46.0 (7)*	40.9 (7)
Dynamic fertigation – Fertygacja dynamiczna (F)	8.1 (1)	23.2 (3)
Seasonal water dose – Sezonowa dawka wody	84.5 (19)	133.9 (27)

* in parenthesis, the numbers of nitrogen or water applications are given – w nawiasach podano liczby alikacji azotu lub wody

High dose of organic nitrogen was applied in 2004 due to a low (50 kg N·ha^{-1}) amount of mineral nitrogen contained in the soil profile (0-60 cm) before potato planting. In 2005, in the soil there were 80 kg N·ha^{-1}. Moreover, in 2004 a higher (in comparison with 2005) expected total tuber yield was assumed for calculations. The remaining part of plants requirement for nitrogen was supplemented with a mineral type of this element used in the form of water solution (fertigation), according to the static (treatment E) and dynamic (treatment F) options, (Table 1). In static fertigation, nitrogen doses and the time of their applications were based on the nitrogen balance at the beginning of the growing period, directly after planting. In dynamic fertigation, on the other hand, nitrogen doses and the time of their application were set day by day, during plant growing. Drip-feed lines of the irrigation system with pressure compensation NetaFim company (water emitters situated every 35 cm) were placed under soil surface (5 cm), on the ridge of every furrow. Efficiency of a single emitter was ca. 1.6 dm^3 per hour. The system was additionally equipped with a fertilizer pump, which made easy application of ammonium nitrate solution possible during the irrigation procedures. Drip irrigation and fertigation control were carried out using the Decision Support System DSS [Battilani et al. 2003, Battilani et. al. 2006]. Years of investigation were characterised by a rather low precipitation sum, 283 and 257 mm for years 2004 and 2005, respectively, with the long-term average for Jadwisin equal to 364 mm (Table 3). Year 2004 was cooler with a lower amount of global radiation and more profitable water balance in comparison with 2005. Moreover, it was characterised by an even precipitation distribution, which is more profitable for potato growing. On the plots, chemical control of phytophthora, Colorado potato beetle, and weeds was performed.

Table 3. Characteristics of the meteorological conditions during potato growing period according to the Campbell weather station located at Jadwisin
Tabela 3. Charakterystyka warunków meteorologicznych w okresie wegetacji ziemniaka według stacji meteo Campbella zlokalizowanej w Jadwisinie

Specification – Wyszczególnienie	Year – Rok	
	2004	2005
Cumulative degree-days air temperature[1], °C day Suma temperatur efektywnych powietrza, °C dzień	1790	1848
Global radiation[2] – Promieniowanie całkowite, MJ·m^{-2}	1838	1902
Precipitation – P: opady, mm	283	257
Reference evapotranspiration[3], mm ETo: ewapotranspiracja potencjalna, mm	477	526
Climatic water balance[4], mm P – ETo: klimatyczny bilans wodny, mm	-195	-268

[1] cumulative degree-days air temperature calculated with the threshold of 2°C for the period between the emergence and growing termination – suma temperatur efektywnych powietrza obliczona z progiem 2°C dla okresu pomiędzy wschodem a końcem wegetacji [Mazurczyk et al. 2000]
[2] global radiation calculated for the period between the emergence and growing termination – promieniowanie całkowite obliczone dla okresu pomiędzy wschodami a końcem wegetacji
[3] reference evapotranspiration calculated for the period of April – September – ewapotranspiracja potencjalna obliczona dla okresu od kwietnia do września
[4] climatic water balance calculated as above – klimatyczny bilans wodny obliczony jak wyżej

For the analyses, 8 plants were taken of every one of the 6 field experiment treatments, after 3, 4, 5, 7, and 9 weeks after the emergence and after the natural drying of leaves, that is after growth termination. Following values of the days after emergence

(DAE) corresponded to them: 22, 29, 36, 50, 64, and 105. On every date, the dry matter of leaves, stems, and tubers was determinated. Harvest index (HI) was calculated by dividing the dry matter of tubers obtained on a particular harvest date by the total plant dry matter, which consisted of the tuber yield of a given date and the maximum dry matter of the above ground part increased by 25%, since it is accepted that root and stolon dry weight makes up ¼ part of the maximum above ground biomass [Beukema and Zaag 1990]. Obtained results were evaluated statistically by the variance analysis. Significance of the differences was estimated using the t-Student's test.

RESULTS AND DISCUSSION

Among cultivated plants, potato is characterised by the highest values of harvest index. Contemporary potato cultivars, grown in temperate climate zones, in favourable agrometeorological conditions reach the most often HI values, for the final crop, within the range of 0.70 to 0.85 [Jefferies and MacKerron 1989, Beukema and Zaag van der 1990, Vos 1997, Belanger et al. 2001]. In literature, it is possible to find reports even about 90% (HI = 0.90) biomass distribution to tubers [Victorio et al. 1986, Beukema and Zaag 1990]. For comparison, in cereals HI values between 0.3 and 0.6 dominate [Hay 1995]. Results presented in this work, contained within the range of 0.7-0.8 (Table 4-5), are thus consistent with the ones presented in the above quoted literature.

Table 4. Final tuber yield, dry matter of the above ground part of potato plants, and harvest index depending on the treatments of nitrogen fertilization and water irrigation (mean values for 2004 and 2005)

Tabela 4. Końcowy plon bulw i masa części nadziemnej roślin oraz współczynnik plonowania w zależności od kombinacji nawożenia azotem i nawadniania (średnie z lat 2004 i 2005)

Specification – Wyszczególnienie	Treatment – Kombinacja						$LSD_{0.05}$ $NIR_{0,05}$
	A	B	C	D	E	F	
Tuber dry matter – Sucha masa bulw, $t \cdot ha^{-1}$	7.53	9.67	10.23	12.16	14.24	12.89	3.45
Maximum dry matter of leaves and stems increased by 25% – Maksymalna sucha masa liści i łodyg zwiększona o 25%, $t \cdot ha^{-1}$	2.52	3.39	3.21	3.63	4.60	4.29	0.37
Harvest index – Współczynnik plonowania	0.75	0.74	0.76	0.77	0.76	0.75	–

Table 5. Final tuber yield, dry matter of the above ground part of potato plants, and harvest index depending on the years of the experiment (mean values for treatments A – F)

Tabela 5. Końcowy plon bulw, masa części nadziemnej roślin oraz współczynnik plonowania w zależności od lat badań (średnie z kombinacji A – F)

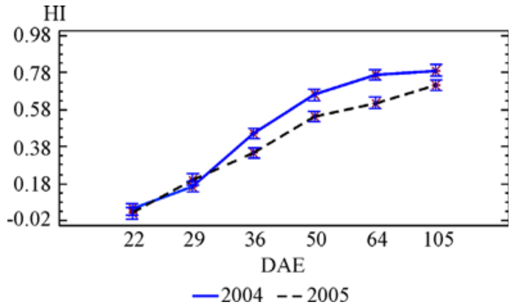
Specification – Wyszczególnienie	Year – Rok		$LSD_{0.05}$ $NIR_{0,05}$
	2004	2005	
Tuber dry matter – Sucha masa bulw, $t \cdot ha^{-1}$	10.90	11.34	ns – ni
Maximum dry matter of leaves and stems increased by 25% – Maksymalna sucha masa liści i łodyg zwiększona o 25%, $t \cdot ha^{-1}$	3.00	4.22	1.13
Harvest index – Współczynnik plonowania	0.78	0.73	–

ns – ni – non-significant differences – różnice nieistotne

In the described experiment, potato plants were grown in 6 treatments (A-F) diversified in regard to their supply with nitrogen and water, Table 2. Diversified nitrogen fertilisation was achieved by the use in every year of identical doses of organic fertiliser (treatments B, D, E, and F), as well as supplementary mineral nitrogen fertilisation (treatments E and F). Adjustment of supplementary nitrogen fertilisation and irrigation to the dynamics of the uptake of these substances by plants was possible with the use of subsurface drip irrigation technology joint with liquid mineral nitrogen fertilisation. Use of the Decision Support System (DSS) assured the precise use of mineral nitrogen and keeping up similar to the optimal soil humidity condition during growing period [Battilani et al. 2006, Mazurczyk et al. 2006]. Value of the highest tuber dry matter yield, obtained on object E (14.2 t·ha^{-1}), (Table 4), was smaller only by ca. 10% from the potential yields of mid-early potato cultivars, to which studied in the present experiment Triada belongs, verifies positively the used method of irrigation and fertilisation of this plant [Mazurczyk et al. 2004]. Such a high degree of the use of yield potential in this treatment shows similar to optimal growing conditions, which were assured, among others, by the applied irrigation and nitrogen fertilisation. The highest tuber yield of treatment E was obtained with harvest index equal to 0.76. It did not differ from the values of this parameter in the remaining treatments contained in a narrow range: from the smallest 0.74 (object B) to the highest (0.77) in treatment C, in spite of the occurrence of significant differences in the accumulation of the dry mass of tubers as well as the above ground parts, (Table 4).

According to the data presented in literature, potato harvest index decreases with the increase of nitrogen dose [Vos 1997, Mazurczyk and Lis 2000, Belanger et al. 2001]. Results presented in this work did not show the existence of the above relation. Probably this discrepancy was caused by the method of nitrogen application. In the above mentioned works, the whole amount of nitrogen dose was used during potato planting, which led to the excess of nitrogen – particularly after the application of higher doses, and consequently to an excessive growth of the above ground plant parts, that is HI decrease. Lack of the decrease in the HI values in treatments E and F (Table 4) confirms in practice that used in our experiment application of supplementary nitrogen doses was adjusted to the current nutritional requirements of potato plants. Jefferies and MacKerron [1989] also showed lack of the effect of potato plant irrigation on HI values reached after growing termination. Those authors presented a similar to the one showed in this work (Fig. 1) course of the changes in the harvest index during growing period.

Higher values of harvest index were shown in 2004 (starting from the 36-th day after emergences) in comparison with 2005 (Table 5, Fig. 1). This increase was stated in all the studied objects. Increased biomass distribution to tubers occurred in 2004, which was characterised by a smaller sum of air temperatures and global radiation in comparison with the growing period of 2005 (Table 3). At the same time, in 2004 more favourable humidity conditions occurred, which is reflected by, among others, a smaller value of climatic water balance: 195 mm for 2004 and 268 mm for 2005. In both years of the research, similar dry mass yield was obtained, which amounted to ca. 11 t·ha^{-1} (Table 2). This yield was obtained with a diversified harvest index: 0.78 and 0.73, respectively for years 2004 and 2005. Reason of HI diversification was significantly higher, by 1.2 t·ha^{-1}, maximum dry mass of the above ground plant part in 2005. Therefore, climatic conditions of the growing period modified to the highest degree the harvest index.



Dates of samplings expressed as DAE: days after emergence – DAE: liczba dni po wschodach

Fig. 1. Changes in the harvest index (HI) during the growing period
Rys. 1. Zmiany współczynnika plonowania (HI) w okresie wegetacji

CONCLUSIONS

1. Diversified supply of the potato plants of the mid-early cultivar Triada with nitrogen and water did not change the values of the harvest index.
2. Climatic conditions of the growing period modified to the highest degree the distribution of biomass to tubers and the above ground potato parts.
3. Increased distribution of dry matter to tubers was promoted by a cooler and more humid growing period with a lower global radiation.

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WSPÓŁCZYNNIK PLONOWANIA ZIEMNIAKA W ZALEŻNOŚCI OD ZAOPATRZENIA W AZOT I WODĘ

Streszczenie. Materiał do badań pochodził z doświadczenia polowego przeprowadzonego w IHAR Jadwisin (52°29' N; 21°03' E). Średnio wczesna odmiana Triada była uprawiana w latach 2004 i 2005 na 6 kombinacjach zróżnicowanych pod względem ich zaopatrzenia w azot organiczny i mineralny oraz wodę. Dawki wody oraz azotu mineralnego w postaci płynnej (fertygacja) ustalane były przy wykorzystaniu komputerowego programu wspomagania decyzji (DSS). Zróżnicowane zaopatrzenie roślin ziemniaka w azot i wodę nie zmieniło istotnie współczynnika plonowania, którego wartość mieściła się w zakresie od 0,7 do 0,8. W obu latach badań uzyskano zbliżony plon suchej masy bulw, około 11,0 $t \cdot ha^{-1}$, przy zróżnicowanym współczynniku plonowania wynoszącym 0,78 w 2004 i 0,73 w 2005 roku. Zwiększona dystrybucja suchej masy do bulw wystąpiła w roku 2004, charakteryzującym się niższą sumą temperatur powietrza i promieniowania całkowitego oraz korzystniejszym bilansem wodnym w porównaniu z okresem wegetacji 2005 roku.

Słowa kluczowe: azot organiczny i mineralny, fertygacja azotem, nawadnianie kroplowe, współczynnik plonowania, ziemniak

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