ACTA SCIENTIARUM POLONORUM *Acta Sci. Pol., Hortorum Cultus 9(4) 2010, 111-120*

DEPENDENCE OF THE YIELD OF MUSHROOMS [*Agaricus bisporus* (Lange, Sing)] ON THE APPLIED SUBSTRATE

Marian Gapiński, Wanda Woźniak, Joanna Murawska, Mirosława Ziombra

Poznań University of Life Sciences

Abstract. Substrate yield-forming properties and their impact on common mushroom yields were evaluated in the course of the performed experiments. All substrates for mushroom cultivation were characterised by considerable variability of yield-forming characteristics. The following yield-forming factors in mushroom cultivation were analysed: weight of substrate in $kg \cdot m^{-2}$ of cultivation area, the method of substrate preparation, substrate moisture content at filling of the cultivation chamber, amount of substrate dry matter in $kg \cdot m^{-2}$ of cultivation area, ammonia concentration in phase II substrate after pasteurisation. The highest mushroom yields were obtained from phase III substrate. An increase of the substrate dry matter per square metre of cultivation area by 1% led to a significant increase in the yield of mushrooms.

Key words: mushroom, phase II substrate, phase III substrate, yield

INTRODUCTION

Polish mushroom industry underwent dramatic organisational and technological changes in 1990. They included advanced specialisation, primarily in substrate production. Other significant transformations involved the process of substrate production by specialised modern compost production plants. The introduction of the so-called bulk pasteurisation made it possible to supply mushroom producers with large quantities of spawned substrate or substrate totally overgrown with mycelium. This type of substrate is supplied to mushroom growers most frequently in the form of pressed blocks wrapped in thermoplastic foil or in bulk. However, substrates from different producers are characterised by considerable variability in yielding. Buying substrates from specialised compost production plants, initially phase II, but recently mainly, phase III substrate, mushroom producers expect selective products of superior quality than that produced on site.

Corresponding author – Adres do korespondencji: Marian Gapiński Departament of Vegetable Crops, Poznan University of Life Sciences, e-mail:gapinski@up.poznan.pl

This study presents results of investigations aiming at the evaluation of substrates for mushroom cultivation currently available on the Polish market. Substrates of phase II and III from different producers were analysed. The results refer to dependencies between the examined factors and the obtained yields of mushrooms.

MATERIAL AND METHODS

The substitute substrate used for mushroom cultivation was prepared by three specialised substrate manufacturing plants. Substrates from individual enterprises were designated as follows:

A – phase II substrate, in the summer and winter periods, from a total of 24 cultivations,

A1 – phase II substrate, in the winter, spring and summer periods, from a total of 38 cultivations,

B – phase III substrate, throughout the year, from a total of 173 cultivations.

The substitute substrate was hard straw of winter cereals with broiler droppings and gypsum mixed at a weight ratio of 1000 : 800 : 75. Wetted and mixed substrate constituents were subjected to classical biothermal fermentation in bunkers with aerated floors commonly used in mushroom production. The process lasted for 10–12 days, during which the substrate was turned over three to four times. Bulk substrate pasteurisation was always carried out in special pasteurisation chambers at the production plant. Temperature and humidity inside pasteurisation chambers were controlled by computers equipped with appropriate software. Bulk pasteurisation lasted for 7–9 days [Bayer et al. 2000].

The following parameters were treated as yield-forming factors: weight of substrate in $kg \cdot m^{-2}$ of cultivation area, method of substrate preparation, substrate moisture content in % at the filling of the cultivation chamber, the amount of substrate dry matter in $kg \cdot m^{-2}$ of cultivation area. The following ammonia concentration after pasteurisation in % dry matter in phase II substrate.

All cultures were run at the same private mushroom farm in a completely independent design assuming the entire area of the cultivation chamber as a replicate. The entire mushroom farm included 40 air-conditioned plastic foil tunnels of 286 m^2 each.

Investigations consisted in analyses of selected substrate yield-forming traits. All the variables, including the descriptive analysis of the dependence of the yield as the dependent variable, were subjected to statistical analysis, which made it possible to determine the effect of yield formation. Determination of the correlation function and regression coefficient made it possible to assess changes in yield levels at changes in individual values of the examined independent variables.

Statistical analysis was performed using "Statistical" software and the Microsoft Excel descriptive statistics analysis as well as based on theories presented by [Eland 1964] and [Kala 2005]. The linear regression function was applied in the descriptive analysis. The goodness of fit coefficient (R^2) determines the goodness of fit percentage of the regression function to reality, i.e. what part of the variability of the dependent variable (y) is explained by the variability of the independent variable (x).

The following components of the descriptive statistics were used to assess research results of phase II and phase III substrates: mean value, standard deviation, coefficient of variation, range, median, variations, average deviation from the mean, minimum and maximum values of examined traits and their effect on yield levels [Romanens 1999].

RESULTS

Phase II substrates for mushroom cultivation. The weight of substrate bulk supplied to individual cultivation chambers varied. On average, the amount of substrate bulk was around 91.63 kg·m^{-2} (tab. 1), with the range amounting to as much as even 26 kg·m^{-2}. Indices of variation in substrate traits based on the descriptive statistics were not high. Standard deviation amounted to 7.02, while the coefficient of variation was estimated at 7.66%. The median was slightly lower than the mean (90.80 kg·m^{-2}), variance was 49.26, whereas the average deviation from the mean was estimated at 5.81, respectively.

Table 1. Characteristics of phase II substrate for mushroom cultivation from plant "A"
Tabela 1. Charakterystyka podłoża fazy II. do uprawy pieczarek z wytwórni „A"

Statistics – Statystyka	Substrate Podłoże kg·m^{-2}	Humidity Wilgotność %	Dry matter Sucha masa kg·m^{-2}	Ammonia Amoniak % dm, s.m.	Yield Plon kg·m^{-2}
Mean – Średnia	91.63	68.26	29.06	0.07	18.60
Standard deviation Odchylenie standardowe	7.02	2.07	2.56	0.02	2.35
Coefficient of variation Współczynnik zmienności, %	7.66	3.03	8.80	32.19	12.65
Range – Rozstęp	26.00	11.35	10.25	0.08	10.83
Median – Mediana	90.80	68.20	28.59	0.06	18.73
Variance – Wariancja	49.26	4.27	6.54	0.00	5.54
Deviation from mean Odchylenie od średniej	5.81	1.22	2.05	0.02	1.67
Minimum – Minimum	79.90	60.65	25.44	0.04	15.07
Maximum – Maksimum	105.90	72.00	35.69	0.12	25.90

Average substrate moisture content amounted to 68.26%. Standard deviation was 2.07, indicating a relatively small coefficient of variation of 3.03%. The range indicating absolute variation of the analyzed moisture content reached 11.35 percentage points, with the lowest being 60.65% and the highest – 72%. The median was very similar to average indicating symmetrical distribution in time. Variation was estimated at 4.27, while the average deviation from the mean amounted to 1.22.

The mean substrate dry matter content was 29.06 kg·m^{-2}, with the range slightly over 10 kg·m^{-2}, ranging from 25.44 kg·m^{-2} to, 35.69 kg·m^{-2}. The calculated standard deviation was 2.56, while the coefficient of variation in this case reached 8.80%. This means

that the values in individual cultures differed on average by 8.8%. The median was slightly lower than the mean (28.59), variance amounted to 6.54, whereas the average deviation from the mean was assessed at 2.05.

A significant level of correlation with the obtained yield was observed in the case of the substrate moisture content. The goodness of fit coefficient of the assessed correlation utilised the result at 45.51%, indicating its uniformity. It was a negative correlation, which means that in the case of moisture content reduction by one percentage point, the yield would increase by 0.7687 kg·m^{-2}.

The amount of dry matter in the substrate was also significantly correlated with the obtained yield. In this case, the correlation was r = 0.5579. The assessed regression function of the yield dependence on dry matter was significant. This means that the increase in dry matter weight by 1 kg·m^{-2} improved yields by 0.51 kg·m^{-2}. The goodness of fit coefficient amounted to 31.13% (tab. 2).

Table 2. Correlation and regression of mushroom yield on phase II substrate from plant "A"
Tabela 2. Korelacja i regresja plonu pieczarek na podłożu fazy II. z wytwórni „A"

Dependence of yield in kg·m^{-2} on: Zależność plonu w kg·m^{-2} od:	Correlation coefficient r Współczynnik korelacji r	Regression function Funkcja regresji	Goodness of fit coefficient R^2 Współczynnik dopasowania R^2 %
Substrate weight Masy podłoża, kg·m^{-2}	0.0706	y = 0.0237x+16.431	0.50%
Moisture content Wilgotności, %	-0.6746*	y = -0.7687x+71.071	45.51%
Dry matter Suchej masy, kg·m^{-2}	0.5579	y = 0.5134x+3.6849	31.13%
Ammonium, % in dm. Amoniaku, % w s.m.	-0.2949	y = -24.822x+19.823	8.70%

Substrate weight was least, non-significantly correlated with the levels of mushroom yield. In the case of supplier "A" no effect was found for the weight of phase II substrate in kg·m^{-2} of cultivated area. The assessed regression function only in 0.5% explained the yield value in comparison with changes in the weight of phase II substrate.

The obtained negative correlation between ammonia content and mushroom yield was not significant (r = -0.2949). It was found that an increase in ammonia content by 1/100% in phase II substrate dry matter reduced yields by 0.248 kg·m^{-2}. The goodness of fit coefficient of the assessed regression function was at 8.7%, which means that ammonia content had only a slight effect on yield reduction.

Generally speaking, it can be said that, no significant differences were found in terms of the evaluated yield-forming traits between substrates supplied by procedures "A" and "A1" (Tab. 1 and 3). Mean substrate weight was found to be 95.86 kg·m^{-2}, i.e. a value slightly lower than the median (96.60 kg·m^{-2}). Standard deviation amounted to 7.96, while the coefficient of variance was estimated at 8.30%. However, in comparison with the mean value, the range was relatively high, higher than in substrate "A" and amounting to 39.50 kg·m^{-2}, which showed that the substrate weight per unit area was markedly different in consecutive cultures (tab. 3).

Table 3. Characteristics of phase II substrate for mushroom cultivation from plant "A1"
Tabela 3. Charakterystyka podłoża fazy II do uprawy pieczarek z wytwórni „A1"

Statistics – Statystyka	Substrate Podłoże kg·m^{-2}	Moisture content Wilgotność %	Dry matter Sucha masa kg·m^{-2}	Ammonia Amoniak % dm, s.m.	Yield Plon kg·m^{-2}
Mean – Średnia	95.86	69.93	28.81	0.05	19.386
Standard deviation Odchylenie standardowe	7.96	2.71	3.39	0.01	4.169
Coefficient of variation Współczynnik zmienności, %	8.30	3.88	11.77	28.25	21.50
Range – Rozstęp	39.50	9.95	13.67	0.06	10.10
Median – Mediana	96.60	70.17	28.64	0.05	19.88
Variance – Wariancja	63.29	7.35	11.51	0.00	17.38
Average deviation from mean Odchylenie od średniej	6.16	2.27	2.71	0.01	3.08
Minimum – Minimum	74.10	64.10	21.49	0.03	16.38
Maximum – Maksimum	113.60	74.05	35.16	0.09	26.48

Mean substrate dry matter (tab. 3) was 30.07 kg·m^{-2}, which was slightly higher than the median (29.83 kg·m^{-2}). The standard deviation was determined at 2.71, while the coefficient of variation was estimated at 9.02%. The range in this case was assessed at 9.95 kg·m^{-2}.

Phase II substrate supplied by producer "A1" from 38 cultures was characterised by considerable variability. The biggest effect on yields was found for substrate weight in kg·m^{-2} of a given cultivation area (r = 0.6177). The estimated regression function indicates that an increase of substrate weight by one unit would increase yields by 0.1979 kg·m^{-2}. The goodness of fir coefficient of the estimated regression function was 38.16% (tab. 4).

Table 4. Correlation and regression of mushrooms yields on phase II substrate from plant A1"
Tabela 4. Korelacja i regresja plonu pieczarek na podłożu fazy II z wytwórni „A1"

Yield dependence in kg·m^{-2} on: Zależność plonu w kg·m^{-2} od:	Coefficient of correlation r Współczynnik korelacji r	Regression function Funkcja regresji	Gooodness of fit coefficient R^2 Współczynnik dopasowania R^2 %
weight of phase II substrate masy podłoża fazy II, kg·m^{-2}	0.6177	y = 0.1979x+1.281	38.16
moisture content wilgotność podłoża, %	-017.61	y = -0.1969x+33.47	3.10
dry matter sucha masa, kg·m^{-2}	0.5914	y = 0.4706x+6.3421	34.97
ammonia – amoniak	0.0817	y = -15.502x+20.296	0.67

A significant value of the correlation coefficient was also found for the amount of dry matter in kg·m^{-2}, which reached r = 0.5914, whereas the estimated function of regression y = 0.4706x + 6.3421. The goodness of fit coefficient of the regression function amounted to 34.97%.

The correlation coefficient with moisture content in the "A1" substrate with the obtained yield was found to be close to zero. In such a situation, further discussion of the other elements of descriptive statistics was pointless (tab. 3 and 4).

The correlation between ammonia content and the yield was very low, reaching barely r = -0.0817 and making further analysis useless. However, the regression function of this dependence with the goodness of fit coefficient was assessed at only 0.67%. This indicates that an increase in ammonia content reduced the yield. The range of ammonia content in the substrates fluctuated from 0.03 to 0.09% dry matter. This confirms that its higher concentrations are toxic to mycelium.

Phase III substrates for mushroom cultivation. The weight of phase III substrate had a significant effect on yield levels. The average quantity of substrate per cultivation area unit was 81.15 kg·m^{-2}, which was close to the median value (80.77 kg·m^{-2}). Standard deviation amounted to only 4.28 and the estimated coefficient of variation was low (5.27%). However, in comparison with the mean value, the range of data was relatively high, reaching 30.20 kg·m^{-2}. This proves that the weight of substrate per unit area differed in consecutive cultures. The extreme values fluctuated from: the minimum of 62.70 to the maximum 92.90 kg·m^{-2} (tab. 5).

Table 5. Descriptive characteristics of phase III substrate for mushroom cultivation from plant "B"
Tabela. 5. Charakterystyka opisowa podłoża do uprawy pieczarek fazy III. z wytwórni „B"

Statistics – Statystyka	Substrate Podłoże kg·m^{-2}	Moisture content Wilgotność %	Dry matter Sucha masa kg·m^{-2}	Yield Plon kg·m^{-2}
Average – Średnia	81.15	63.63	29.54	24.84
Standard deviation Odchylenie standardowe	4.28	3.42	3.42	2.90
Coefficient of variance Współczynnik zmienności, %	5.27	5.37	11.59	11.66
Range – Zakres	30.20	17.60	17.04	15.10
Median – Mediana	80.77	63.83	29.54	25.14
Variance – Wariancja	13.31	11.63	11.73	8.40
Average deviation from the mean Odchylenie od średniej	3.23	2.83	2.89	2.30
Minimum – Minimum	62.70	55.13	21.19	16.10
Maximum – Maksimum	92.90	72.73	37.28	31.20

Substrate moisture content was significantly negatively correlated with mushroom yields. The mean moisture content was 63.63% at the standard deviation of 3.42, which indicates that generally substrate moisture content differed from the mean by only 5.37%. The range indicating the absolute variability of substrate moisture content amounted to 17.60 percentage points. The lowest substrate moisture content in this study was 55.13%, while the highest – 72.73%. The median was very similar to the mean, confirming a symmetrical distribution of the value. The variance was estimated at 11.67 and the average deviation from the mean was 2.83.

The mean amount of dry matter was 29.54 kg·m^{-2} of the cultivation area at the range of 18.38 kg·m^{-2}, with the lowest quantity of 27.27 kg·m^{-2} and the highest – 44.87 kg·m^{-2}. Thus standard deviation amounted to 3.78, while the coefficient of variation in this case was as high as 11.58%. The median was equal to the mean dry matter content, whereas the average deviation from the mean was estimated at 2.89.

In the case of the discussed system the substrate dry matter content was characterised by the highest and also significant correlation with yield levels. This correlation amounted to r = 0.5223. The estimated regression function of yield depending on dry matter content is described by the following formula: y = 0.4419x + 11.786. This means that an increase in dry matter content by 1 kg·m^{-2} causes an increase in yield by 0.4419 kg·m^{-2}. The goodness of fit coefficient in this case was 27.28% (tab. 6).

Table 6. Correlation and regression of mushroom yields growing on phase III substrate from plant "B"
Tabela 6. Korelacja i regresja plonu pieczarek na podłożu fazy III. z wytwórni „B"

Dependence of yield in kg·m^{-2} on: Zależność plonu w kg·m^{-2} od:	Correlation coefficient r Współczynnik korelacji r	Regression function Funkcja regresji	Goodness of fit coefficient R^2 Współczynnik dopasowania R^2 %
substrate weight masa podłoża, kg·m^{-2}	0.3581	y = 0.2425x+5.1614	12.83%
moisture content wilgotność, %	-0.4407	y = -0.3737x+48.622	19.42%
dry matter sucha masa, kg·m^{-2}	0.5223	y = 0.4419x+11.786	27.28%

Table 7. Mushroom yield characteristics depending on substrate supplier
Tabela 7. Charakterystyka plonu pieczarek w zależności od dostawcy podłoża

Statistics – Statystyka	Substrate producer and phase Wytwórnia i faza podłoża		
	„A" phase II A" faza II	„A1" phase II „A1" faza II	„B" phase III „B" faza III
Average yield – Średni plon, kg·m^{-2}	18.60b[#]	19.39b	24.84a
Standard deviation – Odchylenie standardowe	2.35	4.17	2.90
Coefficient of variance – Współczynnik zmienności, %	12.60	21.50	11.66
Range – Zakres, kg·m^{-2}	10.83	10.10	15.10
Variance – Wariancja	5.84	17.38	8.40
Minimum – Minimum, kg·m^{-2}	15.07	16.38	16.10
Maximum – Maksimum, kg·m^{-2}	25.90	26.48	31.20

[#]Numbers having the same letters do not differ significantly – liczby o tych samych literach nie różnią się istotnie

A comparison of mushroom yields grown on phase II and phase III substrates. Mushroom yields harvested from phase II substrate were similar, irrespective of the substrate supplier (tab. 7). Yield repeatability was distinctly higher on substrate "A" than on substrate "A1". Mushroom yields were highest on the "A1" substrate. The uni-

formity of mushroom yields from phase III substrate was highly unsatisfactory, as the range amounted up to 15.10 kg·m^{-2}.

DISCUSSION

Recently dynamic development has been observed in mushroom production in terms of both technological processes and technical conditions. In Poland, common mushroom production in the last two decades matched that of the leading EU countries as far as global yields are concerned. Progress was achieved thanks to specialisation. Initially, mushroom growers purchased the required substrate components and tunnel, prepared the substrate, ran the actual cultivation, harvested and sold their yields. At present, due to specialisation, each of the above-mentioned stages is taken care of by specialised enterprises and the producer is involved only in the cultivation and harvest of the yield.

The success or failure of mushroom cultivation depends on a multitude of interrelated factors. Considerable differences were found in terms of the analysed characteristics of experimental substrates, irrespective of the substrate supplier or substrate phase.

In his report [Romanens 1999] reported analytical results of two thousand substrate samples collected during the filling of cultivation chambers and showed that when traditional methods of substrate preparation were employed, despite certain seasonal changes, substrates of constant parameters can be obtained throughout the year. In our experiments the results concerning assessed substrate traits showed considerable differences between maximum and minimum values. These differences occurred irrespective of the phase (II vs. III) of the applied substrate and irrespective of the supplier.

In a majority of the examined phase II substrates, ammonia (NH_4^+) content within the admissible limits, although sometimes it exceeded the upper limit by 0.02% DM. The performed analyses of individual cultures showed that its content resulted in slight yield reductions. Investigations conducted within this study corroborate research results reported by [Treschow 1944] and [Gerrits 1988], in which ammonia was toxic to mushroom mycelium. The non-significant coefficient of the negative correlation of yield with ammonia content was characterised by a negative value of r = -0.2949 for the "A" substrate and r = -0.0817 for the "A1" substrate.

The objective of substrate pasteurisation is to remove undesirable microorganisms and pests as well as ammonia [Kinrus 1977], and according to [Bayer et al. 2000], in order to achieve this it is essential to reconstruct the microflora destroyed during the hygienising phase. Research results presented in this study indicate that phase II substrate was not always completely free from ammonia, which could have been the cause of lower yields in comparison with the yields harvested from phase III substrate. Therefore, it can be said that phase II substrate used in this study may not have been fully selective, as it was stated by [Overstijns 1981]. Grogan et al. [2000] proved that a selective substrate, when analysed for the presence of mould fungi, should not contain any other fungi except *Scytalidium thermophilum*.

Gerrits [1969] maintained that yield linear regression analysis indicates a significant dependence (r = 0.91) of yield level on the quantity of organic matter and moisture content in the substrate. The results pertained to traditional cultivations, since pasteuri-

sation, incubation and yielding took place in the same cultivation chamber. The results obtained in this study corroborated the dependence of the common mushroom yields grown on phase II and III substrates on the amount of substrate dry matter in $kg \cdot m^{-2}$ cultivated area.

Steineck [1982] claimed that mushroom yields depend on the quantity of substrate per square meter of the cultivation area, which was confirmed by the yields obtained from phase II substrate supplied by producer "A1". In the case of phase III substrate, significantly higher yields were observed, even though the weight of this substrate was lower in comparison with phase II substrate. This proves that phase III substrate productivity was significantly higher than that of phase II substrate, since dry matter content of all the three substrates was similar. Middlebrook [2004] claimed that in Holland since 1993 common mushrooms have been cultivated exclusively on phase III substrates. In Poland less than 20% of mushroom production was produced on phase III substrates in 2003, but an upward trend has been observed since that time. This approach was corroborated by yields from our investigations, which were significantly higher in this study for phase III substrate in comparison to yields from phase II substrate.

According to Dalsem Mushroom Project BV [2002], the optimum substrate moisture content following pasteurisation during the filling process of the cultivation chamber should range from 70 to 72%, while [Romanes 1999] recommended the maintenance of substrate moisture content at 75.34 ± 1.07%. On the other hand, according to [Noble et al. 2008] the best mycelium growth rate is achieved when substrate moisture content after pasteurisation amounts to 72%. The moisture content results of phase II substrate were lower and this, among others, may explain the recorded lower yields, because 1% deviation in moisture content above or below the optimum level reduces yields by 0.5 $kg \cdot m^{-2}$. All the presented results were characterised by a distinctly higher range of moisture content.

Deming [2001] maintained that common mushroom growers provide the foundation for the development of mushroom industry and production of good quality substrate. If not all observations and comments of mushroom growers reach substrate producers, then sooner or later problems are bound to occur. Only constant, mutual, exchange of information between mushroom growers, substrate producers and science can create conditions for the development of good mushroom and substrate production. The results of these investigations show that these interrelationships are still not understood properly in Poland.

CONCLUSIONS

1. All the evaluated substrates, irrespective of the phase of preparation and supplier, differed in terms of their yield-forming traits and yield.
2. The highest yields were obtained on phase III substrate.
3. Mushroom yields obtained from phase III substrates were affected by the amount of dry matter, substrate weight and its moisture content.
4. Ammonia found in phase II substrate after pasteurisation had a negative effect on mushroom yield.

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ZALEŻNOŚCI OD PODŁOŻA PLONU PIECZARKI *Agaricis bisporus* (Lange, Sing)

Streszczenie. Polskie pieczarkarstwo w ostatnim dziesięcioleciu ubiegłego wieku przeszło zasadnicze zmiany. Rozwinęła się daleko posunięta specjalizacja w etapach produkcji. Do istotnych zmian należy zaliczyć proces produkcji podłoża. Wprowadzenie pasteryzacji w tak zwanej masie umożliwiło zaopatrywanie producentów w dużą ilość podłoża z wsianą grzybnią lub podłoża całkowicie opanowanego przez grzybnię. Przeprowadzono ocenę cech plonotwórczych podłoży i ich wpływ na plon pieczarki. Wszystkie podłoża do uprawy pieczarek charakteryzowały się dużym zróżnicowaniem cech plonotwórczych. Jako czynniki plonotwórcze w uprawie pieczarek analizowano: masę podłoża w $kg \cdot m^{-2}$ powierzchni uprawy, sposób przygotowania podłoża, wilgotność podłoża podczas napełniania hali, ilość suchej masy podłoża w $kg \cdot m^{-2}$ powierzchni uprawowej, zawartość amoniaku po pasteryzacji w podłożu fazy II. Najwyższy plon pieczarek uzyskano na podłożu fazy III. Wzrost ilości suchej masy podłoża na metrze powierzchni uprawy o jeden procent powodował istotne zwiększenie plonu pieczarek.

Słowa kluczowe: pieczarka, podłoże fazy II, podłoże fazy III, plon

Accepted for print – Zaakceptowano do druku: 13.08.2005