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Waste Paper as an Alternative for Casing Soil in Mushroom (*Agaricus bisporus*) Production

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Abstract: Three experiments were carried out in order to investigate the possibility of replacing peat casing soil by waste paper in mushroom production. The experiments included the treatments of uncomposted shredded paper, composted paper and composted paper with nitrogen addition. The data revealed that uncomposted shredded paper was not suitable for the growth and production of mushroom headbodies. The same results were also obtained with the treatments of composted waste paper but to a lesser extent. Only composted waste paper with nitrogen addition that showed promising results however still not up to the standard casing soil (peat). The results are discussed in relation to the physical and chemical properties of paper.

Keywords: Mushroom, *Agaricus bisporus*, waste paper, casing soil and production.

INTRODUCTION

Mushrooms are an important source of nutrients for humans[1,2] and also for preventing and/or alleviating some diseases such as cancer and heart diseases[3-5]. In addition, mushrooms are well accepted in the industrial countries because the low content of energy and its dietary effect. Therefore the consumption of mushrooms in the world is growing every year. Recently the consumption came up to 3,072,000 t per year[6]. The consumption of the different mushroom types differ as well as the amount of produced mushrooms in the continents. The highest consumption of mushrooms exists in Oceania with 2.36 kg per capita in 2002 followed by Europe with 1.52. The lowest consumption exists in the Middle East and Africa with about 0.05 till 0.01 kg per capita. The mushroom production in the Middle East countries is without any economic importance. On the other hand the consumption of *Agaricus* mushrooms in such region is increasing very rapidly and at the moment in Lebanon, mushroom is consumed about 30 tons per month (LEBANESE MINISTRY OF AGRICULTURE 2003, pers. communication). This indicates that the amount of production is by far less than what is consumed in this region. Analyses of the situation concerning the production of mushrooms in Lebanon expect a very good economical result. In the Middle East exists the same trend as in the EU concerning the consumption of fresh mushrooms. Therefore the reasons should be investigated why the mushroom production is not developed in this region. Of big importance is to compare the existing production requirements with the needs of mushrooms. For instance it is very important for successful cultivation of *Agaricus* mushrooms are the availability of high quality substrate and casing soil. At the moment no industry producing such materials are available in Lebanon. It is principally not a problem to create such industry, but very important is to check the availability of useful resources. Investigations for planning of a mushroom industry showed especially a lack of peat as main substance of casing soil. Therefore it is very important especially in the arid subtropics and tropics to search for materials which can replace peat. There are some investigations with this aim[7], but still several questions are not solved. It is the aim of this study to answer the following questions:

- Which material can replace peat in the dry areas? Is it possible to use e.g. waste paper for such purpose?
- The technology for preparing of such material.

MATERIALS AND METHODS

In order to answer the two questions mentioned above the research work was carried out in three experiments and arranged to follow the following steps:

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1. The examination of using un-composted shredded waste paper as casing soil directly without any further treatments in comparison with the standard peat casing soil.
2. The effect of composting on the characteristics of shredded waste paper used as casing soil.
3. Composting of waste paper with different dosage of nitrogen.
4. Investigation of the best thickness for this new material.

All experiments were carried out in the experimental farm of the institute of Horticultural Sciences of Humboldt University of Berlin. The composting of the paper and the cultivation of mushrooms were carried out in different underground rooms. The two rooms for the cultivation of *Agaricus* mushrooms had an area of about 35 m^2. The rooms were cleaned and disinfected before starting with the experiments. The temperature changes in the rooms were in all seasons marginal and an average temperature of 20 °C could be kept. An electrical heater was used to regulate the room temperature. The humidity and the CO_2 content were frequently measured, but there was no possibility to influence these factors automatically. The differences of the humidity in the rooms were not very high during the experiments. The CO_2 content in the air was measured, however, there was no measurement for contents above 2200 ppm CO_2.

The *Agaricus* mushrooms were cultivated in plastic boxes or plastic bags. The boxes or bags were standing on the ground; every repetition was grouped together. These groups were placed differently to randomize the experiment.

The substrate used in all experiments was prepared from the Weser-Champigon Dohme GmbH & Co. The basic component of this substrate is horse manure. This mushroom substrate was inoculated with *Agaricus* spawn and ready for casing. The strain Le Lion 36 was used in the experiments.

As control the standard casing substrate (peat) was used in all experiments. The pH-value was adjusted with lime to have a pH of 7.5. The chemical composition of the standard casing (peat) and of paper before composting showed high differences in the content of cellulose, the C/N ratio as well as the content of Mn, Cu and Zn (Table 1). The high content of Carbon in paper showed the necessity to compost this waste paper and to add nitrogen. The thickness of the standard casing soil (peat) was in all experiments about 5.0 cm while for all paper treatments were 3.0; 5.0 and 7.5 cm.

The chemical composition of paper used in the experiments is shown in Table 1. In the experiments different types of used writing paper, mainly recycling paper) and newspaper were used. In one experiment German and Lebanese newspaper were compared. In framework of these experiments it was not possible to analyse the different types of writing paper concerning their chemical compounds (bleach, e.g. chlorine products, binder and others). Also the types of ink use for the newspapers could not be analysed. But it is expected that Lebanese paper is more environment friendly because following the new policy in Lebanon more environmental friendly printing ink with less heavy metals have to be used for newspaper.

The paper was shredded with a machine ‘Ideal’ in strips of about 5 mm wide. In the first experiment it could be observed the disadvantages of these strips. When the strips became wet during the mushroom cultivation, they bond together and it was difficult for the mushrooms to grow. Therefore in one experiment the paper was formed to small globules. This was carried out by cutting of waste newspaper into sheets of 20 x 20 cm. The paper was then moisturized and placed in a mixer for 20 minutes where paper pieces were rolled up and became the form of globules. The diameter of these globules was 10 mm in dry condition, but was extending till 25 mm during the cultivation.

Paper composting: Waste paper was collected and shredded in 0.5 cm width with different lengths. Eight plastic pots were filled each with five kilograms of shredded paper for composting. Each pot had five side-holes in order to keep enough aeration and prevent temperature from rising to critical levels. The electrical heater was used to regulate room temperature in a range of 18°C. Temperature of the composted paper was monitored by 50 cm-long mercury thermometer, one in each pot. Temperature of the compost did not fall below 18°C and not higher than 38°C.

In the beginning of composting, water was added to each pot abundantly until drain was enough and paper was completely wet. Water then was added when necessary to keep the substrate moisture. Water was added equally to each pot in every watering-time. The moisture content in this compost was around 60%. Pots were covered with plastic sheets in order to reduce surface evaporation. Compost was mixed thoroughly every while to have homogenous temperature and composting process.

In order to accelerate the composting process, C/N ratio had to be narrowed by adding nitrogen. Nitrogen was added in the form of potassium nitrate with 98% purity. In every experiment, with exception to the first experiment, half of the composting pots were treated with nitrogen and the other half had null addition (control). In one experiment there were four nitrogen rates applied: null (control), 0.3, 0.5 and 0.7 g 100 l^{-1}. The amount of nitrogen calculated in the form of potassium nitrate was dissolved in two litres of tape water and added to each treatment. The composting time was 2 months.

The physical properties were analysed of paper and peat. In the experimental station of the Institute for horticultural sciences the pore volume, water capacity and air capacity using the Air-pycnometer[8] was measured.

Harvest was carried out once a week and a total of six harvests were collected. Total weight and number of heads were recorded in each harvest. Average weight of individual heads was calculated. Dry matter content in some harvests were measured by measuring the fresh weight of some *Agaricus* mushroom heads and their dry weight after drying in the oven for three days on 108°C.Chemical analysis was carried out according to Chapman and Pratt[9]

The statistical analysis of the experimental data was carried out using ANOVA one way analysis. Significant differences were calculated at $P < 0.05$. The LSD method was used in all statistical analyses. SPSS package version 11.0 was used for these processes.

RESULTS AND DISCUSSIONS

Uncomposted waste paper as casing soil: In the first experiment with *Agaricus* mushrooms, un-composted waste paper was used as casing soil on mushroom beds. The results indicated clearly that the waste paper have to be composted to have an effect as casing soil. Later on waste paper was composted without and with supplements.

Composting without supplements: Composting process is known to change the properties of the materials used[10].

The composting takes about 60 days. The compost was kept all the time moist. During the composting the temperature rose till 33 °C, some days later the compost seemed to be ready for use. It was decided the compost is in good condition as casing material after lowering the temperature. The compost could be evaluated also by the range-scale for the smell of compost from the German Association for Compost. Following this scale this compost had number 5. This range is not really satisfactory but it could be assumed that a longer composting would not give better results.

The analysis of the composted paper showed that pH value was slightly different than that of peat. Meanwhile, water holding capacity of the composted paper was 24 % lower than that of standard casing material (peat). Electrical conductivity (EC) was also lower but in an acceptable range that does not prevent mushroom growth.

Table (1 and 2) summarizes some physical and chemical properties respectively of shredded paper in comparison to that of peat.

Composting of waste paper with addition of nitrogen: The results of the experiments with waste paper composting without supplements were not satisfactory. As shown in Table (1), the C/N ratio of shredded paper is quite wide. Vedder[11] advised to use substrate with a C/N ratio of 16. Therefore nitrogen was added to the waste paper before composting in different dosages. A reason to add nitrogen was to enhance speed of composting process. Therefore this ratio had to be reduced in order to stimulate the activities of the micro-organisms present in the waste paper. Physical parameters of all variants were measured after composting (Figure 1). It is visible that the physical structure of the composted paper is highly influenced by the composting method. Variants with higher dosage of nitrogen were more intensively composted, this leads to an increasing water-capacity and decreasing air-capacity. Due to the composting process the density of the compost increased. This experiment pointed out also a high correlation between the density and the air-capacity of the composted paper. The structure of peat is similar to the variant composted with the highest dosage of nitrogen. The influence of higher nitrogen dosage on the physical structure should be investigated in future.

The evaluation of compost with different nitrogen dosage by the range-scale for the smell was between 5 and 4.

Effect of waste paper as casing for *Agaricus* mushroom cultivation: Treatments of un-composted paper as casing soil did not give any results. Therefore the results from these variants are not included.

Effect of waste paper without supplements as casing soil: The investigations of composting paper without supplements were also not very successful. Therefore the results in the variants with paper as casing soil were not included in the evaluation of the data. Furthermore the fruit quality was unacceptable in these variants; because some fruit bodies were malformed and grew very slowly (Figure 2). Those malformed fruits had a very strong consistence compared to those from the variant with peat as casing material. It is also to mention that in the variants with paper as casing the number of fruits was lower compared with peat but the size was much bigger.

Table 1: Chemical composition of waste paper and standard casing soil (peat)

Substance	Unit of measure	Paper	Peat
Lignin	%	11.6	2.7
Cellulose	%	50.1	8.9
Raw-ash	%	18.8	39.2
Organic matter	%	80.5	61.0
Carbon	%	46.8	35.5
C/N ratio		169:1	47:1
Total N	%	0.30	0.78
Ammonia	%	0.0	0.0
Boron	ppm	0.45	0.57
Phosphorus (P_2O_5)	%	0.05	0.48
Sodium (Na_2O)	%	0.20	0.5
Potassium (K_2O)	%	0.13	0.07
Calcium (CaO)	%	3.50	32.1
Magnesium (MgO)	%	0.20	0.71
Iron	%	0.35	0.15
Manganese	ppm	350.0	0.85
Zinc	ppm	125.0	25.0
Copper	ppm	50.0	10.0

Table 2: pH, EC and Water holding capacity (WHC) of waste paper and peat used as casing soil for *Agaricus* mushroom production

Material	pH	EC mS/cm	WHC (ml water/100g DW)
Waste paper	7.7	0.2	248
Standard (Peat)	7.5	0.5	325

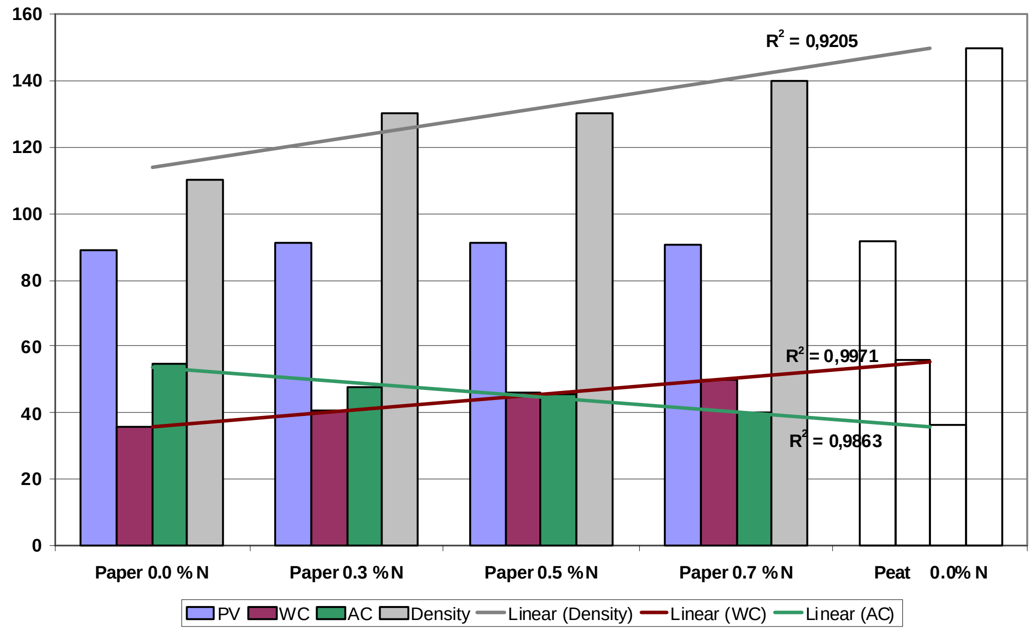
Effect of composted-paper with addition of nitrogen as a casing cover: Adding nitrogen to the shredded paper during composting seemed to affect the composting process and the physical properties of the composted paper (Figure 1).

These effects reflected on the growth of *Agaricus* mushroom heads. The mushroom substrate was grown completely with mycelium in all variants. The growth of the mycelium in the casing soil was different. In casing material consisting from composted paper the mycelium was very week and there were many dead primordia of *Agaricus* mushroom in the upper layer of the casing soil.

Although the number of *Agaricus* mushroom heads produced was smaller in all paper variants compared to the control (standard substrate), this production was obviously higher compared to that of the previous experiment which produced only few or no *Agaricus* mushroom heads under paper treatments.

An important question is the evaluation of the growth rate of the *Agaricus* mushrooms. The data were collected from the variant composted paper with 0.7 % nitrogen and a thickness of the layer with 5 cm. Figure (3) shows the average growth rate of mushroom heads (mm/h). It is obvious that the growth rate of mushroom heads grown with a peat casing was almost twice higher then that of mushroom heads grown with paper casing. The difference was highly significant.

Figure (4) shows the total number of *Agaricus* mushroom heads harvested during the experiment. It can also be seen that within paper treatments, addition of 0.7% nitrogen gave the highest production compared to all other variants with paper as casing material. Thickness of 5 cm casing with composted waste paper gave a good result. Comparing the weight of the harvested *Agaricus* mushrooms (Figure 5) with the fruit number (Figure 4) it is evident a higher total fresh weight than the fruit number in all variants with paper casing. That means the average



Index: Water-capacity: Y = 20.28 X + 35.645
Air-capacity: Y = 54.46 – 19.72 X
Density: Y = 40.19 X + 112.43

Figure 1: Physical parameters of composted and un-composted paper and peat after composting.

Fig. 2: Well formed (left) and malformed (right) *Agaricus* mushroom grown in plastic bags with composted and un-composted paper used as casing soil.

individual mushroom weight in those variants was much higher than from peat. This means that average weight of individual mushroom heads (figure 6) was negatively related to the total number of harvested *Agaricus* mushroom.

The results with composted and un-composted paper as casing material were very weak. As mentioned, therefore these results are not shown. Even in this situation these un-successful experiment concerning casing with waste paper, should be discussed. Similar results were obtained earlier [7] where composted shredded paper was used without supplements as a casing material. The mushroom yield in those experiments was very low. Yeo and Hayes[12] used paper and waste paper pulp stored for a short period of time. The mushroom yield was also not satisfying if it was used as casing material. The low yield of the *Agaricus* mushrooms using waste paper for casing may be due to the low CO_2 concentration in this

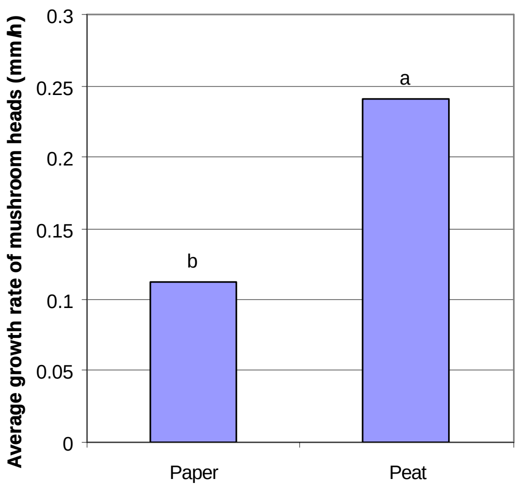


Fig. 3: Growth rate of mushroom heads (mm/h) grown under two types of casing soil.

layer. The loose structure of paper casing could be a reason for the insufficient CO_2 concentration[13]. This lack of CO_2 leading to a limited sporophore formation. There are good effects on the primordial development in the casing layer if this layer was enriched with CO_2[14, 15]. Another possibility is to cover the surface of the casing soil with a polyethylene film to increase the CO_2 concentration between the casing soil and the film [16]. The reason for a low CO_2 concentration could be also the marginal existence of microorganism in the waste paper. The malformation in fruit bodies observed in some of the variants with waste paper casing could be caused of the unfavourable physical structure. Such malformation of mushroom can appear if the hyphal morphology of mycelium is changed [17]. The strong consistence of these mushrooms can be caused by the low water content in the casing layer (The water-capacity of paper is 24 % lower

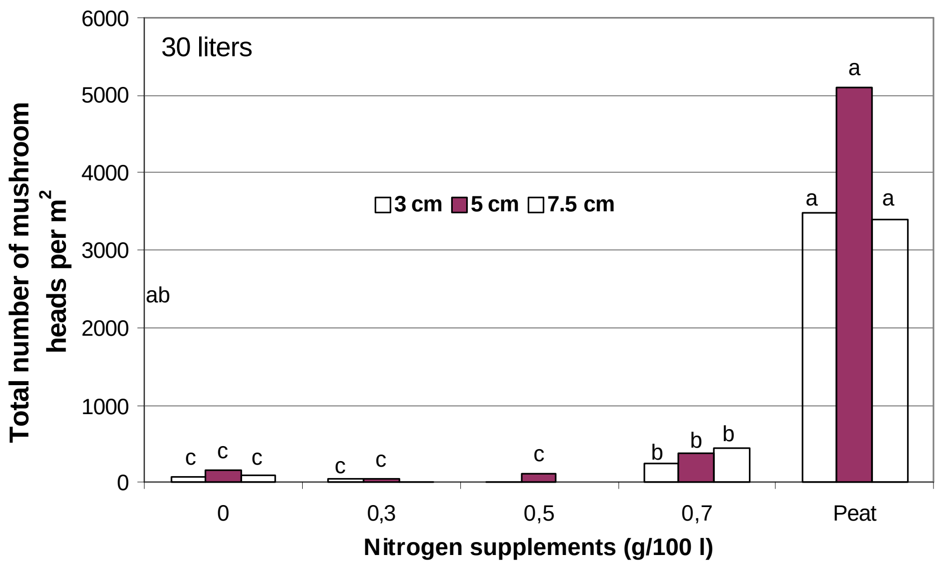


Fig. 4: Total number of harvested *Agaricus* mushroom heads grown under three thickness (3, 5 and 7.5 cm), two types casing soils (peat and composted paper) and two volumes of substrate. Composted paper was treated with different nitrogen rates during composting (0.0, 0.3, 0.5 and 0.7 %). Different letters indicate significant differences at $p<0.05$.

than that of peat) and the slow growth of the mushroom heads. According to Kalberer [18], 32-46 % of water content in the fruit bodies of mushroom is taken up from the casing soil this could explain the low water content in the fruit bodies.

In the experiments with supplements the high efficiency of adding nitrogen before composting of waste paper could be clarified. The highest dosage (0.7 g 100 l^{-1}) can be recommended for composting of paper. This nitrogen rate can improve the activity of microorganisms to regulate the C/N ratio of composted material. The effect of nitrogen addition was positively related to mushroom production. The good result with a casing layer using composted paper with 0.7% nitrogen can be due to the higher water content of composted paper in comparison to other nitrogen supplementary rates.

Despite this observed positive effect on mushroom growth using additional dosages of nitrogen with composted paper, mushroom production was still much lower compared to the control (peat treatment). The reason could be the unsuitable physical structure and chemical properties of the composted paper. Therefore the structure should be improved. Adding of supplements as sand or organic waste materials could be a good solution

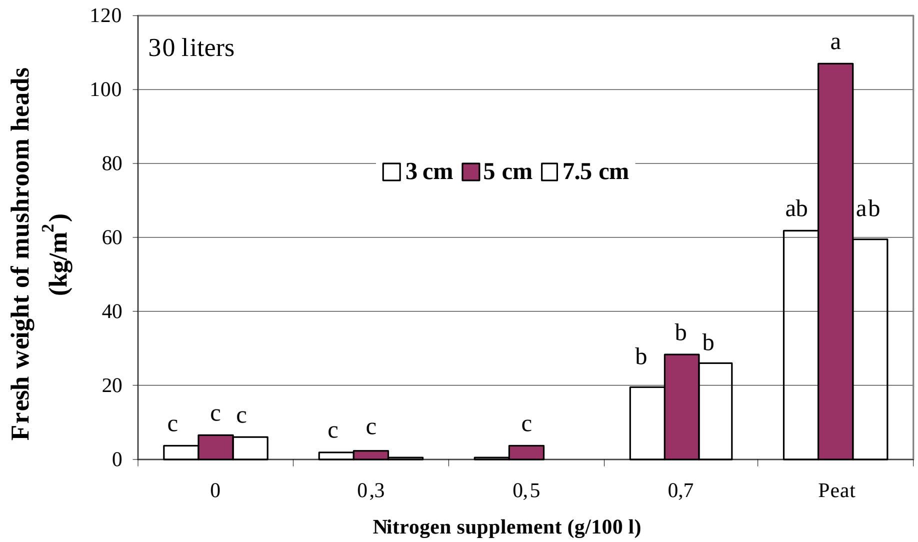


Fig. 5: Total fresh weight of harvested *Agaricus* mushroom heads grown under three thickness (3, 5 and 7.5 cm), and two types (peat and composted paper) of casing soils. Composted paper was treated with different nitrogen rates during composting (0.0, 0.3, 0.5 and 0.7 %). Different letters indicate significant differences at $p<0.05$.

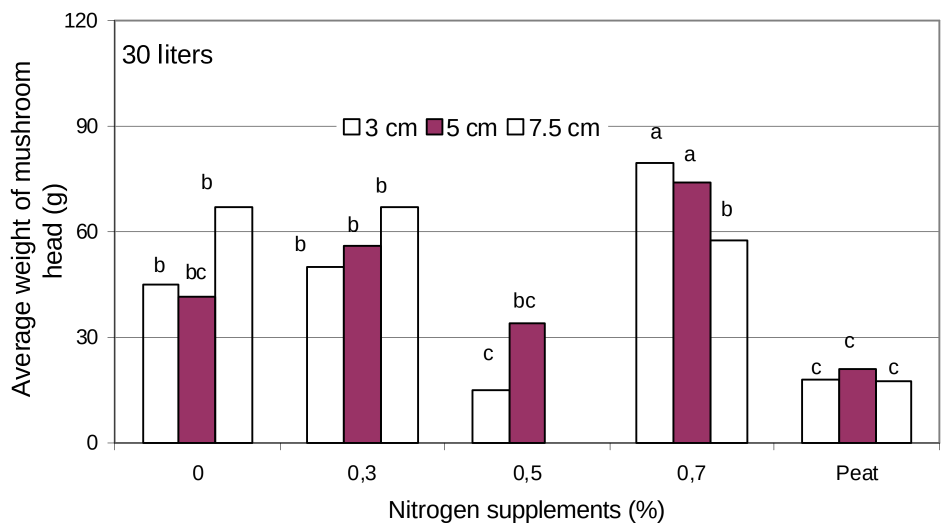


Fig. 6: Average weight of individual harvested *Agaricus* mushroom heads produced under different thickness and nitrogen additions of casing soils.
Different letters indicate significant differences at $p<0.05$.

to get a better porosity. The general effect of casing with composted paper is visible. The reason for a better effect of the highest thickness of the casing layer (7.5 cm) is not clear. On one hand some authors described the importance of a high casing layer for *Agaricus* mushrooms the fruit-body formation[19-21], on the other hand the casing layer have to be very loose, otherwise many p rimordia can not penetrate the casing substrate. In case of unfavourable structure of the casing layer the thickness of 5 cm seemed to be more efficient.

Another reason for the much lower result compared with peat casing could be the low CO_2 concentration which encourages the mushroom fruit-body formation[13-16].

It was found a different correlation between the number of mushrooms and their fresh weight in variants with paper casing and peat. The very high weight of mushrooms if the casing material was composted paper can also be due to the less competition for nutrients in the substrate and the casing material.

It can be concluded that composting waste paper with the addition of nitrogen to lower C/N ratio gave promising results to be used as casing soil in mushroom production however, some improvement in the physical characteristics of composted waste paper must be done to obtain production comparable to the standard casing material (peat).

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