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Effect of different types and doses of nitrogen fertilizers on yield and quality characteristics of mushrooms (*Agaricus bisporus* (Lange) Sing) cultivated on wheat straw compost

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Abstract
The most important prerequisite for a successful mushroom production is a high-quality compost substrate. For the present study wheat straw was used as bulk ingredient for the compost substrate preparation. In order to improve the C/N ratio and to accelerate the composting process, all substrate formulas need the addition of nitrogen-rich supplements at the outset of composting. Besides organic nitrogen sources, inorganic nitrogen supplements are also applied, when high-carbohydrate bulk ingredients are used. In the present work four different nitrogen fertilizers (urea (46 % N), ammonium nitrate (33.5 % N), calcium ammonium nitrate (26 % N) and ammonium sulfate (21 % N)) in three doses were applied as nitrogen sources and the effect on yield and some quality characteristics (cap weight, stalk weight, cap diameter, stalk diameter and stalk length) was investigated. The fertilizer application had only an unimportant effect on the cape diameter, which is an important characteristic for the classification of mushrooms, but had a stronger effect on the stalk length, which is also important for the classification. The highest dose of calcium ammonium nitrate produced the significant highest yield at the same time this variant also resulted in good results regarding the investigated quality characteristics.

Keywords: *Agaricus*, mushroom, compost, N-fertilizers

1 Introduction

To prepare high-quality compost is the most important factor for a successful mushroom production. *Agaricus bisporus* is a secondary decomposer, which means that bacteria and other fungi have first to break down the raw materials of the substrate before the mushroom can grow (Volk and Ivors, 2001). In the ready compost substrate the inactivated microorganisms serve as an important nutrient source for the mushrooms (Beyer, 2003; Schnitzler, 2003).

Straw-bedded horse manure supplies a very suitable basis for growing mushrooms and is the most used substrate for cultivating mushrooms in Europe as well as in the USA and

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Canada. However, horse manure is not always and everywhere available in a sufficient quantity and quality to an acceptable price. Therefore horse manure is often partly or completely replaced by chicken manure. Sheep, cattle and pig manure is only of little importance for mushroom growing, as these manures do not supply a suitable basis for the fermentation of the substrate. Medicament residues of a former treatment of the animals can also have a negative effect on the composting process. For a long time there are attempts to work only with straw substrates (Schnitzler, 2003).

The aim of the mushroom substrate preparation is to produce a medium that is nutritionally sufficient and selective for the mushroom mycelium growth. For an undisturbed run of the composting process, besides a sufficient supply with water, oxygen and nutrients, a balanced C/N ratio must be guaranteed. Therefore, all compost formulas require besides the conditioning agent gypsum the addition of nitrogen-rich supplements (Beyer, 2003). The values given in the references for the desirable nitrogen content at the outset of composting vary between 1.5 % and 2.0 % computed on dry weight basis (Vedder, 1978; Chang and Hayes, 1978; Bozok, 1987; Beyer, 2003). Besides protein-rich seed meals, like soybean meal, cottonseed meal and brewer's grain, commercial fertilizers are used as nitrogen supplements when high-carbohydrate bulk ingredients are used (Beyer, 2003).

For the present work wheat straw was used as bulk ingredient for the compost substrate preparation. Wheat straw consists of 92.5 % total dry matter, 3.9 % protein, 1.5 % fat, 36.7 % fiber, 41.9 % N-free extract, 8.3 % total minerals, 0.21 % Ca, 0.07 % P, 0.62 % N and 0.79 % K (Chang and Miles, 1989). Wheat straw is one of the most uncomplicated materials with which to work (Stamets, 2000). The nitrogen content of wheat straw based compost however, is too low to meet the need of the compost microorganisms for an optimal growth and reproduction. For a successful composting and therefore for a successful mushroom production a readily available form of nitrogen must be added to the substrate at the outset of composting.

The aim of the present investigation was to find out, how the addition of different N -fertilizers in different doses as N-supplement affects the yield and some quality characteristics of the mushrooms.

2 Materials and Methods

The research was conducted at the Mushroom Production Facility of Çanakkale Onsekiz Mart University, Turkey. Four different fertilizer types: Urea (with 46% N), AN (ammonium nitrate with 33,5% N), CAN (calcium ammonium nitrate with 26 % N) and AS (ammonium sulfate with 21 % N), were applied in three different doses (60 g N/bag, 70 g N/bag and 80 g N/bag) as nitrogen sources. Five replications for each treatment, making up a total of 60 plots, were arranged in a randomized complete block design.

The different composts were prepared according the composting timetable as seen in table 1.

The ready composts (ammonia concentration under 0.05 percent) were put in 10 kg black polyethylene bags. To initiate the mycelium growth the bags were kept in a

Table 1: Composting timetable

Day	*Application*
- 4	Bales of wheat straw (316 kg for 60 bags) were opened and watered (water amount calculated with 2,5 t water/t wheat straw).
0	Dry parts of the straw were watered, mixed with bran (0,742 kg/bag). The N doses for each fertilizer variant (60 g N/bag, 70 g N/bag, 80 g N/bag) were added separately and composts were pressed and piled again.
5	Piles were broken up, bran (0,742 kg/bag) and molasses (0,210 kg/bag) were added. Composts were mixed, pressed and piled (1. turn over).
9	Piles were broken up, dry parts were watered and gypsum (0,316 kg/bag) was added. Composts were mixed and piled again but without pressing (2. turn over).
12	Compost piles were aerated and piled again without pressing (3. turn over).
14, 16, 18, 20 and 22	Compost piles were turned over for the 4th, 5th, 6th, 7th, 8th time.
23	Composts were pasteurized.
26	Composts were aerated and mixed.
29	Inoculation of the aerated composts with 60 g mycelium/bag.

production room with a temperature of 20 to 25 °C and moisture content of 85 to 90 %. When a complete colonization of the composts with mycelium was achieved, pasteurized peat from Bolu Yeniçag, Turkey was added as a surface layer (4 cm), to promote mushroom formation. A few days later the room temperature was decreased to 16 to 18 °C and two weeks later the ventilation of the room was increased. During the whole run of the experiment, cultural and technical procedures were applied according to the instructions of Erkel (1993).

During the picking period (breaks) the mushrooms were twisted out before the veil broke and the following data were recorded daily, corresponding with the work of İlbay and Ağaoğlu (1996): Number of mushrooms per bag; yield (g/bag); average cap weight (g/mushroom); average cap diameter (mm); average stalk weight (g/mushroom); average stalk diameter (mm); average stalk length (mm).

Data were analyzed using ANOVA and the differences among the treatment means were separated by the Duncan's multiple range test (SAS, 1996). Due to wet rottenness no yield was obtained from the 80 g N/bag urea application, therefore, statistical analysis was done only with 11 treatments.

3 Results

The results of this investigation are given in the tables 2 (a–g). The effects of treatments were found significant at the 5% level.

3.1 Number of Mushrooms

The results presented in table 2 (a) show significant differences in the number of mushrooms/bag, due to the applied fertilizer type and the interaction of fertilizer type and dose. In the mean of the fertilizer doses CAN resulted the significant highest number of mushrooms/bag and AS the significant lowest. Urea, CAN and AN application show a correlation between increasing dose of fertilizer and the number of mushrooms. The number of mushrooms increased with increasing dose of urea and CAN, but decreased with increasing dose of AN.

3.2 Yield (g/bag)

Table 2 (b) shows a statistically significant effect of the fertilizer type, the fertilizer dose and the fertilizer type/dose interaction on the yield. In the mean of the fertilizer doses, the CAN application produced the significant highest yield and the AS application the lowest. Regarding the interaction of fertilizer type and dose, the significant highest yield was obtained with the highest dose of CAN. Parallel with the number of mushrooms yield increased with increasing dose of urea und CAN and decreased with increasing dose of AN (Tables 2 a and b).

3.3 Average Cap Weight (g)

In the mean of fertilizer doses, the application of urea produced the significant highest average cap weight and the CAN application the lowest. The highest cap weight was obtained with the lowest dose of urea and the lowest with the medium dose of CAN (Table 2 c).

3.4 Average Stalk Weight (g)

The effect of the fertilizer type, the fertilizer dose and the interaction of fertilizer type and dose resulted in significant different stem weights. The single values of the fertilizer/dose interaction vary considerably (Table 2 d).

3.5 Average Cap Diameter (mm)

The effect of the fertilizer type, the dose and the fertilizer/dose interaction on the cap diameter was relatively low, and the differences are only partly statistically significant (Table 2 e).

3.6 Average Stalk Diameter (mm)

In the mean of the fertilizer doses, the application of AS resulted in the significant smallest and the CAN application in the significant greatest average stalk diameter (Table 2 f).

3.7 Average Stalk Length (mm)

In the mean of the fertilizer types, the highest fertilizer dose resulted in the significant shortest average stalk length. In the mean of the doses all fertilizer types produced significant different stem lengths. With regard to the fertilizer/dose interaction, the stem length decreased with increasing dose of urea, AN, and CAN, but the application of AS caused the opposite reaction (Table 2 g).

Table 2: Number of mushrooms per bag

Doses (g N/bag)	*Fertilizer type*				*Mean*
	Urea	*AN*	*CAN*	*AS*	
(a) *Number of mushrooms per bag*					
1 (60)	36 ^{g}	111 ^{c}	80 ^{f}	17 ^{h}	61 ^{B}
2 (70)	81 ^{f}	104 ^{d}	123 ^{b}	4 ^{j}	78 ^{A}
3 (80)	-	92 ^{e}	145 ^{a}	12 ^{i}	83 ^{A}
Mean	58 ^{C}	102 ^{B}	116 ^{A}	11 ^{D}	74
(b) *Yield per bag (g)*					
1 (60)	825 ^{g}	2177 ^{b}	1565 ^{g}	262 ^{h}	1207 ^{C}
2 (70)	1706 ^{d}	1890 ^{c}	1846 ^{c}	61 ^{j}	1376 ^{B}
3 (80)	-	1638 ^{e}	2540 ^{a}	204 ^{i}	1461 ^{A}
Mean	1266 ^{C}	1902 ^{B}	1984 ^{A}	175 ^{D}	1348
(c) *Average cap weight (g)*					
1 (60)	17.05 ^{a}	12.48 $^{e-g}$	13.79 ^{cd}	12.33 ^{fg}	13.91 ^{A}
2 (70)	15.32 ^{b}	13.03 $^{d-e}$	11.03 ^{h}	14.02 ^{c}	13.35 ^{B}
3 (80)	-	13.87 ^{cd}	11.96 ^{g}	13.39 $^{c-e}$	13.07 ^{B}
Mean	16.19^{A}	13.13 ^{B}	12.26 ^{C}	13.25 ^{B}	13.44
(d) *Average stem weight (g)*					
1 (60)	7.21 ^{a}	7.15 ^{a}	5.90 ^{b}	3.28 ^{g}	5.89 ^{A}
2 (70)	5.80 ^{b}	5.10 ^{d}	4.01 ^{f}	2.23 ^{h}	4.29 ^{C}
3 (80)	-	3.96 ^{f}	5.58 ^{c}	4.39 ^{e}	4.64 ^{B}
Mean	6.51 ^{A}	5.40 ^{B}	5.16 ^{C}	3.30 ^{D}	4.94
(e) *Average cap diameter (mm)*					
1 (60)	40.2 ^{b}	36.7 ^{cd}	39.6 ^{b}	36.6 ^{cd}	38.3 ^{B}
2 (70)	36.1 ^{cd}	43.0 ^{a}	37.4 ^{c}	41.2 ^{ab}	39.4 ^{A}
3 (80)	-	37.4 ^{c}	35.0 ^{d}	41.7 ^{ab}	38.0 ^{B}
Mean	38.2 ^{C}	39.0 ^{AB}	37.3 ^{C}	39.8 ^{A}	38.6
(f) *Average stem diameter (mm)*					
1 (60)	22.6 ^{ef}	25.9 ^{bc}	27.2 ^{b}	13.2 ^{g}	22.2 ^{B}
2 (70)	22.6 ^{ef}	25.0 ^{cd}	23.6 ^{de}	20.8 ^{f}	23.0 ^{B}
3 (80)	-	21.4 ^{f}	31.1 ^{a}	24.5 ^{cd}	25.7 ^{A}
Mean	22.6 ^{C}	24.1 ^{B}	27.3 ^{A}	19.5 ^{D}	23.6
(g) *Average stem length (mm)*					
1 (60)	26.3 ^{b}	28.8 ^{a}	22.9 ^{c}	16.5 ^{g}	23.6 ^{A}
2 (70)	20.2 ^{e}	27.4 ^{b}	22.6 ^{cd}	21.8 ^{cd}	23.0 ^{A}
3 (80)	-	19.5 ^{ef}	18.5 ^{f}	21.5 ^{d}	19.8 ^{B}
Mean	23.3 ^{B}	25.2 ^{A}	21.3 ^{C}	19.9 ^{D}	22.2

4 Discussion and Conclusions

Yield increased with increasing number of mushrooms (Table 2 a and b). The highest number of mushrooms and therefore the highest yield was obtained with the highest dose of CAN. The second highest yield was obtained with the lowest dose of AN. As in the medium dose CAN and AN application yielded no significant yield difference, this result suggests that in the highest fertilizer dose the lime content of CAN resulted in a positive effect. The yield difference between the highest and the second highest yield is with 363 g/bag comparatively high, but the additional costs arising from the application of the higher fertilizer dose are with € 0.02/bag relatively low. The application of urea yielded comparatively low yields, but the application of AS produced only very unsatisfactory yields. Similar results were found in previous studies (İLBAY and AĞAOĞLU, 1996; ÖZŞIMŞIR and ARIN, 1996; GÜNAY and A. UZUN, 1996; ZÜLKADIR *et al.*, 1996).

The cap is the preferred part of the mushroom, therefore mushrooms with high cap weights and low stalk weights are desirable. In the mean of the doses the CAN application resulted in a significant lower cap weight than the AN application, but the lowest dose of AN (second highest yield), produced no significant higher cap weight than the highest dose of CAN (highest yield) (Table 2 c). With regard to the stalk weight, the highest dose of the CAN application resulted in a considerable lower stalk weight then the lowest dose of the AN application (Table 2 d).

Even if the differences are partly statistically significant, the different fertilizer applications had only an unimportant effect on the cap diameter. According to the provisions of the Commission Regulation of the European Community (binding since 1 January 2003) for cultivated mushrooms size is determined by the maximum diameter of the cap and the length of the stem (EC, 2002). According to this regulation the minimum cap diameter must be at least 15 mm for closed, veiled and open mushrooms. The average cap diameter of all fertilizer applications of this study, was considerably higher then this limit (Table 2 e). The values of the cap diameters of all fertilizer applications varied lesser than the provisions of the EC Regulation for closed, veiled and open mushrooms allow, if they are market as 'Extra Class' or Classes I and II and the terms 'small' or 'medium' are indicated (specified size ranges for small mushrooms 15-45 mm; for medium mushrooms 30-65 mm).

The highest CAN application (highest yield) produced the greatest stalk diameter, but regarding the stem length (Table 2 f), which is important for the classification, this application produced with in the mean 18,5 mm (1/2 of cap diameter) a comparatively low stem length (Table 2 g). According to the Commission Regulation the maximum stem length (closed, veiled and open mushrooms) must not exceed 2/3 of the cap diameter, when the mushrooms are uncut and 1/2, when the mushrooms are cut (EC, 2002). As in the mean the stalk length of the highest CAN application did not exceed 1/2 of the cap diameter, only very few stalk scraps will be obtained, even if the stalks will be trimmed before the mushrooms are marketed.

The highest doses of CAN (80 g N/bag) produced not only the significant highest yield, but also regarding the most important quality characteristics good results. Therefore, with regard to this study, the application of CAN in a corresponding dose is to be recommended, if inorganic nitrogen sources will be used to increase the nitrogen content at the outset of the mushroom compost preparation.

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