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Effects of fragmentation, supplementation and the addition of phase II compost to 2nd break compost on mushroom (*Agaricus bisporus*) yield

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ABSTRACT

Double-cropping offers growers an opportunity to increase production efficiency while reducing costs. We evaluated degree of fragmentation, supplementation, and addition of phase II compost (PIIC) to 2nd break compost (2BkC) on mushroom yield and biological efficiency (BE%). One crop was extended as a triple crop in which we evaluated effect of compost type, and addition of phase II compost and supplement. All crops involved removing the casing layer after 2nd break and then using 2BkC for the various treatments. Simple fragmentation of the compost increased mushroom yield by 30% compared to non-fragmented compost. Addition of a commercial supplement to fragmented compost increased mushroom yield by 53–56% over non-supplemented, fragmented 2BkC. Fragmented, supplemented 2BkC resulted in a 99% and 108% yield increase over the non-fragmented control depending on degree of fragmentation (3×, 1×, respectively). A 3rd crop of mushrooms was produced from 2BkC, but yields were about one-half that of the 1st and 2nd crops. Double-cropping (and even triple-cropping) offers growers an opportunity to increase bio-efficiency, reduce production costs, and increase profitability. The cost of producing *Agaricus bisporus* continues to rise due to increasing expenses including materials, energy, and labor. Optimizing production practices, through double- or triple-cropping, could help growers become more efficient and competitive, and ensure the availability of mushrooms for consumers.

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1. Introduction

Production of the common cultivated mushroom (*Agaricus bisporus*) is a multimillion-dollar industry in many countries, including the United States. In 2008, sales volume of *A. bisporus* in the United States totaled 360 million kg, valued at 914 million dollars (USDA, 2008). Mushrooms are produced on composted raw materials including hay, straw, poultry manure, gypsum, corn stover and other ingredients. Raw materials and the preparation of selective compost for mushroom production are major cost inputs (Royse et al., 2008; Van Roestel, 1988; Wuest, 1983). Therefore, growers are seeking ways to lower their production costs by increasing bio-efficiency, i.e., producing greater mushroom yield from less raw materials.

Mushroom production is a cyclical process whereby mushrooms are produced in a series of breaks or flushes at approximately 7-d intervals. After two breaks, mushroom production declines rapidly, so that each successive break produces fewer mushrooms. Growers terminate the crop at the end of the 2nd or 3rd break, because it is non-profitable to continue with declining production.

Recent work in our laboratory has shown that it is possible to obtain more than one crop of mushrooms from the same compost (Royse et al., 2008; Royse and Sanchez, 2008a,b; Royse and Chalupa, 2009). The addition of commercial supplements, certain amino acids, and hydrolyzed proteins, increase yields of the 2nd crop. The ability to double-crop mushroom compost provides growers an opportunity to increase bio-efficiency while reducing the amount of "spent" mushroom compost (SMC) that requires disposal. It is estimated that at least 36 million m^3 of SMC are disposed of each year in the United States (AMI, 2005).

During the mushroom crop cycle, compost dry matter loss due to mushroom production may range from 20% to 30% from time of spawning to the end of the second or third break (D.J. Royse, unpublished). If compost is re-supplemented after 2nd break, expected mushroom yield/m^2 is 20–30% lower due to compost dry matter loss from the 1st crop. Therefore, it may be desirable to increase dry matter/m^2 by adding either fresh phase II compost, or by consolidating 2nd break compost to achieve a dry wt similar to the 1st crop.

In order to practice double-cropping, a grower must remove the casing layer after one, two or three breaks and incorporate various supplements into the compost (Royse et al., 2008). Supplements may be incorporated into the compost by spawning machine or by removing the compost from the tray or bed, adding the

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supplement and then returning the supplemented compost to the tray or bed. The type of machine used to fragment the compost may affect extent of fragmentation and subsequently affect aeration, nutrient absorption and water availability from the compost. It is unknown if degree of fragmentation may ultimately influence mushroom yield.

The objectives of this research were to determine the effects of various treatments of 2nd break compost (2BkC) on mushroom yield as follows: (1) degree of compost fragmentation, (2) supplementation with delayed release nutrient, (3) addition of 20% phase II compost, and (4) exploration of the production of a 3rd crop of mushrooms from the same compost or "triple-cropping".

2. Methods

2.1. General crop description

Three cropping experiments were conducted to determine the effect of various treatments of 2BkC compost on mushroom yield and biological efficiency (BE%). Degree of fragmentation and addition of delayed release supplement and their interaction was evaluated in Crop 0806B, while addition of 20% phase II compost and supplement level was evaluated in Crops 0809B and 0810B. Crop 0810C was extended as a triple-crop that evaluated the effect of compost type, as well as addition of phase II compost and supplement. All crops involved removing the casing layer after 2nd break and then using the 2BkC for the various treatments.

2.2. Composts and preparation

Compost for mushroom production was prepared from wheat straw-bedded horse manure mixed with switch grass supplemented with dried poultry manure and gypsum as described by Royse et al. (2008) and Royse and Sanchez (2008a,b). After phases I and II composting, phase II compost was supplemented with Remo's All Season Regular (Remo's Mushroom Services, Avondale, PA), a delayed release nutrient, at 4% dry wt at time of spawning with Sylvan 140 (Sylvan Spawn Co., Kittanning, PA) spawn (a white U1-type hybrid). Spawned, supplemented compost (25 kg) was filled into plastic bins (56 × 44 × 24 cm) and incubated for 16 d at 24 ± 2°C (compost temperature). Immediately after spawning, compost was covered with a woven landscape fabric (Ultra Web 3000 ground cover, Gempler's, Madison, WI). Relative humidity was maintained at ca. 95–98% using a spinning disc humidifier connected to a timer.

Following a 16-d spawn run, casing (sphagnum peat moss and limestone at ca. 80% moisture) was overlaid on the landscape fabric that was used to ease removal of the casing after mushroom harvest. Casing inoculum (CI, Sylvan 140–500 g/m^2) was added to the casing prior to application.

During the case hold (time during mycelial colonization of the casing), air temperature was maintained at 16 °C maintaining compost temperatures at 21 ± 1 °C. Relative humidity was maintained at 95–99% with a spinning disc humidifier. The crop was watered according to visual observations of mycelial growth and moisture content of the casing. Carbon dioxide levels were not controlled but generally ranged between 500 and 1500 ppm. Additional water was applied to the casing after harvest of first break to maintain casing moisture levels near field capacity. Mushrooms were harvested for two breaks and casing removed. The de-cased 2BkC was fragmented, re-supplemented and re-cased. Fragmentation was accomplished by passing 2BkC through a turner fitted with a rotating (>1000 rpm) drum. The drum contained four circumferentially-spaced, longitudinally extended bars that contacted the 2BkC as it was passed through the turner either once (1×) or three times (3×). No attempt was made to quantify particle sizes of fragmented 2BkC for either treatment but 3× was visually finer than 1×.

2.3. Harvesting and determination of yield and biological efficiency

Closed (lamellae not exposed) mushrooms were harvested, counted and weighed daily. At the end of each break, yield and biological efficiency (BE) were determined. BE was defined as the ratio of (g) of fresh mushrooms harvested per dry compost weight (g), including the weight of the supplement, and expressed as a percentage. Compost samples were selected randomly from each crop at spawning and delivered to the Agricultural Analytical Laboratory for moisture and nitrogen content analysis. Yield was expressed as kg/m^2.

2.4. Experimental design and data analysis

All three crops utilized factorial designs (SAS, 2008). Crop 0806B was a 2 × 2 factorial with two degrees of fragmentation (1×, 3×) × two levels of supplement (0, 3.7% dry wt; supplement percentage levels [dry wt] were estimated after determination of compost moisture contents) plus one non-fragmented control treatment (5 treatments × 7 replicates = 35 experimental units). Crop 0809B was a 2 × 2 factorial with two levels of phase II compost (0, 20%) × two levels of supplement (0, 3.53% dry wt) plus one treatment where phase II compost (20%) layered on top of non-fragmented 2BkC and one check treatment with phase II compost (100%) (6 treatments × 6 replicates = 36 experimental units). Crop 0810 was a triple-crop (0810A, 0810B, 0810C). Crop 0810A was the 1st crop with production of two breaks on phase II compost. Crop 0810B used 2BkC from 0810A and was a 2 × 2 factorial with two levels of phase II compost (0, 20%) × two levels of supplement (0, 3.57%). Treatments 1 and 2 had 6 replicates each while treatments 3 and 4 had 17 replicates each (6 + 6 + 17 + 17 = 46 experimental units). More replicates were used for treatments 3 and 4 (with and without 20% phase II compost) because 2BkC from these treatments was used for the 3rd crop, 0810C. Crop 0810C was a 2 × 2 × 2 factorial with two types of 2BkC from Crop 0810B, two levels of phase II compost (0, 20%), and two levels of supplement (0, 3.6%). This crop was produced in plastic bins (17 × 22 × 28 cm) filled with 3.64 kg 2BkC at time of re-casing. For Crop 0810C, there were 8 treatments × 9 replicates = 72 experimental units.

Mushrooms were harvested for two or three breaks depending on the experiment. The SAS program JMP was used to analyze data (SAS, 2008). Data were examined with a one-way analysis of variance (ANOVA) and the Tukey–Kramer Honestly Significant Difference (HSD) was used to evaluate significant differences among treatment means. Data were also evaluated using standard least squares modeling with effect screening (SAS, 2008).

3. Results

Mushroom yields and BEs for the effect of degree fragmentation and supplement added to 2BkC are shown in Table 1. Highest yields were obtained from fragmented 2BkC that was passed through a turner (described earlier) and supplemented with 3.7% nutrient before re-casing. Non-fragmented, re-cased 2BkC yielded only 10.07 kg/m^2 while 1×- and 3×-fragmented, non-supplemented compost yielded 13.45 and 13.09 kg/m^2 (+33.6%, +30%), respectively (Table 1). The addition of 3.7% (dry wt) supplement to 1×- and 3×-fragmented 2BkC increased yield by 108.1% and 99.3%, respectively, compared to the non-fragmented, non-supplemented control. Yields tended to decrease (−2.8%, −4.4% on non-

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