Plant Pathology Bulletin 11:19-24, 2002

Investigations of Paper Mill Sludge as a Component of Container Medium

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Accepted for publication:January 30,2002

ABSTRACT

Ou-Yang, Wu. [1] and Wu, W. S.[1,2] 2002. Investigations of Paper Mill Sludge as a Component of Container Medium. Plant Pathol. Bull. 11:19-24.

Paper mill sludge (PMS), commercial peat and a commercial container medium (BVB No.4) were compared in the greenhouse for use as container media. Composted PMS mixed with peat at ratio of 80% PMS (volume basis) supported plant growth, and relative leaf chlorophyll content of periwinkles comparable to commercial container medium (BVB No. 4). Container medium amended with 50% composted PMS supported similar or better growth of ten different plant species than BVB No.4, except the root length of cosmos and chrysanthemum. Raw PMS supernatant inhibited seed germination of periwinkle. The inhibitory effect was eliminated when the raw PMS was well composted. Composted PMS was compatible with the amended antagonistic microorganism and was good for production healthy periwinkle seedlings.

Key words: Paper mill sludge, plant growth response, potting media

INTRODUCTION

Paper mill sludge (PMS) is waste in the paper processing industry [8,22]. Total annual production in North America is approximately 10 million tons, and in Portugal 35,000 dry tons [4,20]. Until recently, most of the sludge has been discarded in landfill due to increasing scarcity of landfills, high tipping fees, and increasing environmental concerns and governmental regulations [13,15,24]. The utilization of PMS as a soil conditioner or as a component of container media in the nursery industry may provide beneficial alternatives [16,18]. The high cellulose content in PMS improves infiltration and water-holding characteristics, stabilizes soil structure, and increases both cation exchange capacity and nutrient content of barren soils. Consequently, plant growth and production could be increased [6,18,24]. Since the 1950s, PMS has been used for land reclamation [6,7,12], and in forestry or agricultural management projects [9,18,21]. Several plant species have been evaluated for their growth in PMS-amended media, e.g. grains [14,16], grasses [14,23], woody plants [2,3,4,17], and horticultural crops [1]. Most plants grew as well as or better than those grown in medium without PMS amendment. The objective of this study was to determine whether PMS could be used in nursery industry as a substitute for commercial peat in container media.

MATERIALS AND METHODS

One hundred and sixty kilograms of paper mill sludge (PMS) (Taiwan Pulp & Paper Company, Tainan, Taiwan, R.O.C.) mixed thoroughly with 4 kg ammonium sulfate ($(NH_4)_2SO_4$) for facilitating fermentation, was composted in glasshouse for three to six months before use. Piles of PMS were turned over for aeration once every two weeks during composting. Selected physical and chemical characteristics of raw and composted PMS are shown in Table 1. Samples of raw and composted PMS were each suspended in tap water (1:2, v/v) and left overnight at room temperature. The suspension was centrifuged at 7,000 rpm for 20 min. and the supernatant was autoclaved, filtered through the 0.2 μm membrane, or left untreated.

Seed germination

Twenty-five seeds of periwinkle (*Catharanthus roseus* (L.) G. Don. (Known-You Seed Company, Kaohsiung, Taiwan, R.O.C.)) were placed on three layers of filter papers (Whatman No. 1) in a glass petri dish (9 cm diam.) [10]. The filter paper was moistened with sterilized distilled water and used as control. Autoclaved, microfiltered, or untreated supernatant of raw and composted PMS were tested. Seeds were germinated in an incubator at 28℃ with 12-hour diurnal light (276-300 μmol/m^2 sec). Each of the seven treatments was replicated 4 times (4 dishes) and arranged in a completely

Table 1. Physical and chemical characteristics of raw and composted paper mill sludge (PMS) [1]

Parameter	Paper mill sludge	
	Raw	Composted
pH (1:1, H_2O)	7.90	7.80
Electrical conductivity (mS/cm)	8.00	6.33
Solid (%)	23.60	39.40
Sulfate (g/l)	0.23	4.12
Phenolics (μg/l)	0.53	2.40
Tannic acid (mg/l)	3.20	2.50
Chlorine (mg/l)	2.47	0.98
Sodium (g/kg)	—	2.00

1. Measured from the supernatant of a 1:2 (v/v) mixture of PMS and tap water, except the solid.

randomized design. After 7 days of incubation, the percentage of germination was recorded and those germinated were then re-incubated for another 7 days. The 14-day-old seedlings were harvested and oven-dried at 105℃ for 6 hours. This test was repeated twice.

Sludge application rate

Composted PMS was mixed with peat (BAS VAN BUUREN B.V., the Netherlands) in proportions of 0, 20, 33, 50, 67, 80, and 100% by volume. The commercial medium BVB No.4 (BAS VAN BUUREN B.V., The Netherlands) was the control medium. This commercial medium (BVB No. 4) was a mixture of 75% light peat, 25% dark peat and 10 % sand with pH 5.5-6.0. The concentrations of N,P and K in this medium were 60, 55 and 120 mg/L, respectively. Four 3-week-old periwinkle seedlings were transplanted into a plastic pot (12-cm diam.). Plants were arranged in a greenhouse based on a completely randomized design with 5 pots/treatment and grown for 3 weeks without fertilization. At harvest, the height and fresh weight of each plant were measured. The relative content of chlorophyll in leaves of each plant was measured with a chlorophyll detector (SPAD-502, Minolta, Japan). This test was repeated twice.

Plant growth responses

Seeds of tomato (*Lycopersicum esculentum* Mill), sweet pepper (*Capsicum annuum* var. *grossum* Seudt.), cucumber (*Cucumis sativus* L.), African balsam (*Impatiens walleriana* Hook. F.), cosmos (*Cosmos bipinnatus* Cav.), chrysanthemum (*Chrysanthemum paludosum*), Stokes's aster (*Stokesia laevis* (Hill) Greene), dill (*Anethum graveolens* L.), spearmint (*Mentha spicata* L.), and sorrel (*Rumex acetosella* L.) were planted in the 128-cell trays. They were grown in greenhouse for six months based on completely randomized design. The cultural medium was a mixture of composted PMS and peat in the 1:1 ratio (v/v). Twenty seedlings of each species were selected randomly and measured as described above.

Compatiblity of PMS with antagonistic microorganism

Burkholderia gladioli Severini #182, was cultured on potato dextrose agar (PDA) plates at 28℃ for 3 days, washed-off from plates with sterilized distilled water and adjusted to a concentration of 10^9 cfu/ml. *Phytophthora parasitica* Daster was cultivated at 28℃ for 2 weeks in 1:2 (v/v) mixture of V-8 juice and vermiculite. The source of *B. gladioli* and *P. parasitica* was described previously [11]. For each treatment, 3 g inoculum of *P. parasitica* or 400 ml cell suspension of *B. gladioli* #182 was mixed with potting medium consisting of a 1:1 (v/v) mixture of composted PMS and commercial peat. Tap water or unamended vermiculite was used as a control. Each treatment consisted of five pots. Four 3-week-old periwinkle seedlings were transplanted into every pot and grown in greenhouse for 3 weeks. This experiment was arranged in a completely randomized design. This test was repeated three times.

RESULTS

Seed germination

The periwinkle seeds treated with composted PMS supernatant, regardless of whether autoclaved or microfiltered, germinated as well as those treated with sterilized distilled water. However, the corresponding raw PMS supernatants completely suppressed seed germination (Table 2). In contrast, periwinkle seedlings grew significantly better (p=0.05) with composted PMS supernatant compared with sterilized distilled water (Table 2).

Sludge application rate

Growth responses of periwinkle seedlings were increased with increasing proportions of composted PMS in the potting medium up to 50 % composted PMS. Increased concentrations above 50%, composted PMS did not significantly increase plant height or relative chlorophyll content. Sludge application at the rate of 80% or above in the potting medium provided the same fresh weight as commercial medium BVB No. 4. However, more than 33% of composted PMS (by volume) in the container medium provided significantly (p=0.05) greater plant height, fresh weight, and relative content of chlorophyll in leaves than commercial peat only (Table 3).

Plant growth responses

All plant species grown in container medium consisting of PMS+peat (1:1, v/v) grew as well as or better than those grown in the commercial media BVB No.4 except the root lengths of cosmos and chrysanthemum (Table 4). Except dill and sweet pepper, the other eight different species grown in PMS+peat (1:1, v/v) had significantly (p=0.05) greater plant height and fresh weight than those grown in commercial

Table 2. The effects of paper mill sludge supernatant on seed germination and seedling dry weight of periwinkle

Treatment [1]	Germination [2] (%)	Seedling dry weight [3] (mg)
Composted PMS supernatant		
Non-treated	95 a	1.07 b[4]
Autoclaved	95 a	1.13 ab
Filtered	97 a	1.27 a
Raw PMS supernatant		
Non-treated	0 b	0 d
Autoclaved	0 b	0 d
Filtered	0 b	0 d
Sterilized distilled water	96 a	0.69 c

1. PMS was suspended in tap water (1:2, v/v) and centrifuged at 7,000 rpm for 20 min. Supernatant was autoclaved or filtered through 0.2 μm membrane.
2. Seeds were incubated on blotters at 28℃ for 7 days.
3. Seeds were incubated on blotters at 28℃ for 14 days and then oven-dried at 105℃ for 6 h. Variables are means of 25 periwinkle seedlings.
4. Means in the same column followed by the same letter are not significantly different (p=0.05) according to Duncan's multiple range test.

Table 3. The effects of different rate of composted paper mill sludge in peat medium on the growth of periwinkles

Treatment [1]	Height (cm)	Fresh weight (g)	Relative content of chlorophyll [2]
Composted PMS (%)			
0	2.6 [3] d[4]	0.1 d	6.6 c
20	4.7 c	0.5 cd	11.8 bc
33	5.1 c	0.8 c	15.9 b
50	10.7 ab	2.5 b	36.8 a
67	8.8 b	2.5 b	34.7 a
80	10.6 ab	3.2 a	37.6 a
100	8.6 b	2.8 ab	29.9 a
BVB No. 4	12.5 a	3.2 a	20.4 b

1. Composted PMS was mixed with peat on the volume basis, and commercial medium BVB No. 4 was served as control.
2. Variables are the difference of light absorption rate in leaves under two incident rays at the wavelengths of 650 and 940 nm from detector.
3. All variables are means from five replications, four plants per replication. This test was repeated twice.
4. Means in the same column followed by the same letter are not significantly different (p=0.05) according to Duncan's multiple range test.

medium (BVB No. 4). Relative content of chlorophyll of six plant species grown in PMS+peat (1:1, v/v) were greater than those in BVB No.4 (Table 4).

Compatibility of PMS with antagonistic microorganism

Addition of *B. gladioli* #182 to the PMS-amended media did not affect growth of periwinkle (Table 5). Moreover, addition of *B. gladioli* #182 significantly improved the growth of periwinkle in the presence of *P. parasitica*.

DISCUSSION

Paper mill sludge (PMS) has been studied for agricultural use since the 1950's [1,4]. However, the high C/N ratio was considered to be the limitation because it resulted in plant nutritional problems [1,9,23]. For this reason, sludge application rate must be calculated or tested carefully before land amendment or mineral soils reclamation. Chong and Cline [3] indicated that raw paper sludge served effectively as an organic amendment for containerized ornamental shrubs growth when it did not exceed 30% of the medium volume. Chong and Hamersma [4] demonstrated that raw sludge in amounts up to 60% by volume could be an effective amendment for rooting under mist. Ritter *et al.* [14] obtained good results in the greenhouse experiment by amending 33 or 60% sludge in container media. Because the composition of PMS varies with the manufacturing and effluent treatment processes of individual mills, the sludge application rate should also vary. Plant height, fresh weight, and relative content of chlorophyll in periwinkle leaves were increased in this study when more than 33% composted PMS was used to supplement the peat (Table 3). The optimal ratio of composted PMS in potting media was 50% (v/v) or above. The foliage of plant species also had a dark-green sheen suggestive of sufficient essential elements in the PMS-amended (>50% by volume) container media. The concentration of sodium in PMS was high (2.0 g/kg) in this study. However, sodium has been known to be benefit to the growth of several vegetables, e.g. beets, carrots, celery, and rutabaga etc. [19]. The 50% PMS application rate (by volume) was chosen for further studies because of good plant growth of periwinkle and the convenience of preparation.

The supernatant of raw PMS had the inhibitory effects on seed germination. Such effect diminished when the PMS was well composted (Table 2). This suggested that there might be some inhibitors existing in the raw PMS, and that these inhibitors were inactivated and/or destroyed during the processes of composting. Sulfate, phenolics, chlorine and sodium, at the concentrations detected in composted or raw PMS in Table 1, were tested separately for their effects on the growth of periwinkle and *Phytophthora parasitica*. Our results indicated that they did not inhibit their growth (unpublished). DeVleeschauwer *et al.* [5] demonstrated that the presence of organic acids with low molecular weights, (e.g. acetic acid or benzoic acid) during composting could be phytotoxic to plants. These acids could be the main biological inhibitors in uncomposted organic compounds. However, the presence of organic acids was not analyzed in this study.

Results of this study indicated that composted PMS could be used effectively in container nursery culture. Container media amended with 50% composted PMS by volume provided similar effects of plant growth in a number of plants tested compared to commercial media BVB No.4. (Table 4). Antagonist, e.g. *Burkholderia gladioli* #182,

Table 4. Comparative response of 10 different species in a commercial peat compared to the mixture of composted PMS and peat (1:1, v/v)

Plant [1]	Root length (cm)		Plant height (cm)		Fresh weight (g)		Relative content of chlorophyll [2]	
	BVB No. 4	PMS+peat [3]	BVB No. 4	PMS+peat	BVB No. 4	PMS+peat	BVB No. 4	PMS+peat
African balsam	6.59 [4] a [5]	4.53 a	2.47 b	4.56 a	0.15 b	0.35 a	15.50 b	22.48 a
Cosmos	8.34 a	6.15 b	18.50 b	24.22 a	0.48 b	0.77 a	ND [6]	ND
Chrysanthemum	12.35 a	5.98 b	4.36 b	5.55 a	0.18 b	0.51 a	15.80 b	22.05 a
Stokes's aster	5.53 a	5.95 a	9.24 b	14.45 a	0.52 b	0.69 a	31.61 b	39.60 a
Tomato	9.61 a	9.86 a	14.28 b	20.26 a	0.74 b	2.45 a	17.42 b	22.46 a
Sweet pepper	7.81 a	6.17 a	7.95 a	8.81 a	0.50 a	0.70 a	18.36 b	25.64 a
Cucumber	10.56 a	10.63 a	20.04 b	26.84 a	2.24 b	2.90 a	22.60 b	25.48 a
Dill	9.59 a	8.97 a	11.92 a	11.62 a	0.55 a	0.48 a	ND	ND
Spearmint	10.59 a	8.76 a	3.64 b	13.82 a	0.07 b	0.48 a	ND	ND
Sorrel	8.20 a	8.14 a	4.83 b	9.16 a	0.39 b	1.10 a	ND	ND

1. Seeds were sown in each medium and incubated in greenhouse for 6 months.
2. Variables are the difference of light absorption rate in leaves under two incident rays at the wavelengths of 650 and 940 nm from detector.
3. Composted PMS was mixed with peat in the ratio of 1:1 on the volume basis.
4. All variables are means from four replications, five plants per replication.
5. Means of the same parameter followed by the same letter are not significantly different (p=0.05) according to F test.
6. Not determined.

Table 5. The effects of *Burkholderia gladioli* #182 on infection of periwinkle by of *Phytophthora parasitica* in the mixture of composted PMS and peat [1]

Treatment [2]	Root length (cm)			Height (cm)			Fresh weight (g)		
	I [3]	II	III	I	II	III	I	II	III
HCK	10.44 [4] a [5]	10.50 a	10.72 a	4.42 a	4.56 a	4.62 a	1.62 a	1.62 a	1.63 a
DCK	1.60 c	1.62 c	1.65 b	0.89 b	1.05 b	1.05 b	0.19 b	0.19 c	0.21 b
182	9.64 a	10.72 a	11.52 a	3.66 a	4.23 a	4.70 a	1.32 a	1.38 ab	1.61 a
182+PP	5.96 b	7.04 b	8.89 a	2.81 a	3.25 a	3.54 a	1.15 a	1.08 b	1.41 a

1. Container medium was a mixture of composted PMS and commercial peat (1:1. v/v).
2. HCK-medium treated with neither fungus inoculum nor bacterial suspension; DCK-medium treated with *P. parasitica* inoculum only; 182-medium treated with *B. gladioli* #182 suspension only; 182+PP-medium treated with both fungal inoculum and bacterial suspension.
3. I, II, and III represent the first, second and third trial of this test.
4. All variables are means from five replications, four plants per replication.
5. Means in the same column followed by the same letter are not significantly different (p=0.05) according to Duncan's multiple range test.

appeared to compatible with the mixture of PMS and peat (Table 5). Periwinkle blight caused by *P. parasitica* was reported to be controlled by *B. gladioli* #182 [(11)]. This indicated the possibility of utilizing PMS as a component of the container media to produce healthy plant even in the presence of plant pathogen (s). Obviously, composted PMS could be used as a replacement of peat and an effective component of container media.

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摘 要

歐陽瑋[1]、吳文希[1,2]. 2002. 利用紙漿污泥作爲栽培介質的探討. 植病會刊11:19-24. ([1] 台北市國立台灣大學植病系；[2] 聯絡作者，電子郵件：hoganwu@ccms.ntu.edu.tw；傳眞：02-23660148)

在溫室中測試紙漿污染，商用泥炭土及商業栽培介質 (BVB No.4)，當作栽培介質的效益；採用80% 醱酵過的紙漿污泥及 20% 泥炭土的組合，當作栽培介質，可使日日春的生長性狀及葉綠素的相對含量，如同栽種在商用之栽培質中一般。若採用含量爲50% 的醱酵紙漿污泥及 50% 的泥炭土爲栽培介質，栽培的 10 種不同的作物之生長情形，相當或更優於栽種在商用栽培介質中者，上述情形中，除波斯菊及菊花的根長情形外，其餘皆然。未醱酵之紙漿污泥上澄液會抑制日日春的種子發芽，而醱酵後則否；醱酵的紙漿污泥和添加的拮抗微生物爲相容性，因而可生產出健康的日日春幼苗。

關鍵詞：紙漿污泥、植物生長反應、栽培介質