Paper Mill Residuals and Compost Effects on Soil Quality, Snap Bean Diseases and Yield in Wisconsin's Central Sands: Our 5th Year at Hancock, WI

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Improving soil quality in Wisconsin's Central Sands is a major concern for potato and vegetable growers of this region. Enhancing soil quality with organic matter amendments is one exciting and potentially profitable way to improve ecosystem health, which is in line with the mission of the WWF/ WPVGA/ UW Collaboration. Central Wisconsin is home to large-scale paper production, and hence, generation of paper mill residuals (PMR). A growing number of paper mills have received permits to land spread PMR on cropland and there is growing interest in using PMR in vegetable crop production in the Central Sands. In 1998, we began a field trial at the UW Hancock Agricultural Research Station to evaluate the short and long-term effects of building organic matter in sandy soils with annual applications of PMR amendments in a vegetable rotation. Our 2002 snap bean season represents the 5th year of quantifying the effect of raw PMR and PMR composts on soil properties, crop production, and naturally occurring diseases.

Field Design:

We initiated a field trial at the UW Hancock Agricultural Research Station in April 1998. The 2002 field season constituted the fifth year (snap bean) of the second cycle of a three-year vegetable rotation: potato-snap bean-cucumber. The experimental design for the entire rotation is a randomized complete block with amendment type/rate as the main effect (total of 7 treatments). These treatments are replicated five times in plots 15' X 25'(total of 35 plots). Treatments are: 1) raw PMR; 2) PMR composted alone (PMRC); 3) PMR composted with bark (PMRB); and 4) no organic amendment control (the "conventional practices" control). Organic amendments are applied annually over each plot at two rates: 10/15 dt/acre for raw PMR and approximately 17/35 dt/acre for PMRC and PMRB. Amendments are applied and incorporated into the top 6" of soil in mid-late April.

Prior to amending on April 16 in 2002, we divided each plot in half length-wise to achieve two split-plots of 7.5' X 25' areas. One of the split-plots for each treatment received new amendment in 2002, while its companion half remained non-amended. By splitting each organic amendment treatment plot, we were able to evaluate the residual effects (4 years of re-amending plots) of the PMR and PMR composts on soil properties, crop diseases and crop productivity.

Planting and Management:

All plots were planted with snap bean "True Blue" on 3' centers on May 24. All beans received 20 lb. of N starter fertilizer. On June 19, all PMR and PMRC plots received 15 lbs. N/acre, while PMRB and non-amended control plots received 30 lbs. N/acres for their first split-application of N fertilizer (NH_4NO_3). Plots received their 2nd split N-application on July 3 at flowering: all PMRB and control plots received 30 lbs. N/acre, the high rate of PMRC (both split-plots) received 15 lbs. N/acre, and the low rate of PMR and PMRC re-amended this season received 15 lbs. N/acre, while their unamended counterparts were fertilized with 30 lbs.N/acre. Plots amended with the high rate of raw PMR (re-amended and residual plots) did not receive N during the season because this amendment contributed a sufficient amount of N to the crop. Plots were irrigated twice per week and weeds were controlled weekly by hand-hoeing.

Soil Chemical and Physical Measurements:

Total Organic Carbon: During the growing season, we measured total soil carbon and nitrogen before re-amending in 2002 (April 8), one-month after re-amendment (May 13), and one-week prior to harvest (July 15). A composite soil sample consisting of 15 soil cores (1.5" diam. x 6" depth) was removed from each split-plot of all treatments. Soil was dried, sub-sampled, and ground for total C and N analysis.

Mineral N: We measured available N (NH_4-N and NO_3-N) on July 2 by inserting 5 ion exchange membranes (IEM) vertically into the top 15 cm of soil (Cooperband and Logan, 1994), next to the base of the plants in each split plot. This *in situ* method permitted sampling of plots without soil removal.

Bulk density and soil volumetric moisture: We determined bulk density of intact soil cores (3" diam. X 3" depth), which were removed from each split-plot in conjunction with removal of bulk soil for total soil C analysis. Gravimetric soil moisture content was determined on July 2 in the top 6" of soil. Volumetric moisture content was calculated from gravimetric soil moisture and bulk density.

Diseases Measured:

One row per split plot was designated our disease assessment row. After plant emergence, three 3-ft linear row segments were randomly chosen and flagged for assessment of bacterial brown spot (*Pseudomonas syringae* pv. *syringae*) severity during the season. Plant canopy within each 3-ft segment was rated weekly with the Horsfall-Barrett rating scale (Horsfall and Cowling, 1978) beginning on July 9 until harvest. Common root rot (*Pythium* spp. and *Aphanomyces euteiches*) severity was measured July 17. Thirty plants within 1-ft of the disease row, but outside of the brown spot assessment segments, were removed and rated on a disease index scale (Kolbriger et al, Bulletin A3242).

Snap Bean Harvest:

A 10 ft linear row of beans was hand-harvested on July 22 from the disease assessment row in each split-plot. Beans were graded with a rolling grader into sieve size classes 1-3 (5 –10 mm-diameter), 4 (10 mm-diam.), and 5 (11 mm-diam.). The beans were harvested from each treatment/split plot when we determined that roughly 50% of the beans were sieve size 5. After harvest, an oat cover crop was planted to reduce the potential of nitrate leaching.

Results and Discussion:

Table 1: Soil chemical and physical properties influenced by raw and composted paper mill residuals, before and after application of amendments to our Hancock plots in 2002.

	Pre-Amendment (April)			Post-Amendment (July)							
	Total C	Total N	Vol M (%)	Total C		Total N		Vol M		NO_3	
Treatment				+	-	+	-	+	-	+	-
PMR$_L$	23.5	1.81	17.9	24.9	21.8	1.7	1.6	14.0	10.8	6.6	0.7
PMRC$_L$	24.4	1.86	20.3	28.7	26.6	1.7	1.7	16.1	14.8	2.4	1.8
PMRB$_L$	31.4	1.98	18.7	36.1	30.6	1.9	1.9	15.1	12.2	0.6	1.2
PMR$_H$	27.4	1.91	18.2	29.4	24.9	1.8	1.6	13.5	12.3	8.6	0.4
PMRC$_H$	34.2	2.45	22.1	40.8	31.9	2.6	2.1	16.1	13.3	4.1	1.1
PMRB$_H$	43.1	2.31	21.3	55.4	44.1	2.5	2.7	23.4	15.6	0.6	0.2
Control	15.1	1.42	16.2	12.7		1.1		13.1		2.5	
LSD ($P<0.05$)	2.7	0.14	1.9	5.7	5.2	0.3	0.2	3.0		1.9	

Treatments are 1) low rate of raw paper mill residuals (PMRL), 2) low rate of PMR compost with no bark (PMRCL), 3) low rate of compost with bark (PMRBL), 4) high rate of PMR (PMRH), 5) high rate of PMRC (PMRCH), 6) high rate of PMRB (PMRBH), and 7) non-amended control. + = re-amended with organic matter treatment in 2002; - = not re-amended in 2002 (residual effect from previous amendment events). Total C, N, and NO_3 measurement units are Mg / Ha; NO_3 in soil was measured *in situ*.

Soil Properties:

Plots previously amended with PMR or PMR composts, regardless of rate, began the 2002 season with greater soil C as compared to the non-amended control plots (Table 1). Prior to re-amendment with the organic amendments, plots historically amended with either the low or high rate of bark compost (PMRB) contained 2 – 3 times more soil C ($P < 0.05$) as compared to the non-amended plots. Both the low and high rates of both composts enhanced volumetric water content in the soil ($P < 0.05$) over the non-amended control treatment. Moisture content, however, in soil amended with raw PMR was comparable to the control soil. Even so, there was a strong positive correlation between volumetric moisture and amount of soil C ($R^2 = 92\%$, $P < 0.01$) prior to re-amendment with raw PMR, yet this relationship did not exist in the compost treatments ($P > 0.10$). It appears that a factor other than amount of total soil C enhanced volumetric moisture content in the compost-amended soils.

Three months after re-amending with the organic matter amendments, total soil C increased in all of the PMR treatments compared to the controls ($P < 0.05$). In our split-plot application, re-amendment with either rate of raw PMR or the low rate of PMRC did not increase soil C over the residual amount of C in the un-amended companion half of the split plot. There was, however, 19 – 28% more soil C in the split plots re-amended with the high rate of both composts or low rate of PMRB as compared to the unamended half of these treatments. Only re-amendment with the high rate of bark compost increased volumetric water content of the soil compared to the control ($P < 0.05$). Volumetric water content did not differ between the re-amended and non-amended halves of both rates of PMR and PMRC or the low rate of PMRB. There was a significant positive relationship between water content and total C ($R^2 = 32\%$, $P < 0.05$) with re-amendment, but this relationship did not exist in plots left un-amended this year.

The residual soil C in plots amended with the high rate of PMRB from previous years was 3 times greater than soil recovered from the non-amended control plots. Yet, the volumetric moisture in soil with a history of PMRB-application did not differ from that of the control. In fact, even though residual amounts of C in plots previously amended with PMRB were marginally lower (20%) than those amended with PMRB in 2002, the volumetric water content was 33% lower in these residual C plots. Much like what we found in our pre-amendment soils this year, it appears that the increase in soil water content in PMR-compost amended plots depends on soil factors, such as carbon quality (ie. the active fraction), in addition to carbon quantity.

The amount of mineral N in soils was greatly influenced by re-amendment with either PMR or the PMR compost without bark. On average, soil in plots receiving raw PMR contained 15 times more mineral N ($N-NO_3$) compared to plots containing residual amounts of PMR. Both PMR and PMRC contributed a reasonable amount of mineral N with both application rates. From previous years of this study, we expected more NO_3-N from the raw PMR than PMRC. Also consistent with previous years, PMRB did not contribute mineral N during the season.

Disease Severity:

Re-application of PMR amendments significantly reduced common root rot severity ($P < 0.05$) in July (Fig. 1). At the high application rate, all plots re-amended with raw or composted PMR suppressed root rot disease by 57 - 70% compared to the non-amended control treatment. Only the PMR composts suppressed root rot when re-applied at the low application rate. It was not necessary to re-apply a high rate of PMR or either rate of PMRB to their respective plots this year because there was a significant residual effect of these treatments on root rot suppression. Root rot severity was reduced by 84% and 70% in the PMR and PMRB plots, respectively, which did not receive amendment this year. The residual effect of these two amendment types indicates that the disease suppressive effect of these materials is maintained throughout the following growing season. The compost without bark (PMRC), however, did not have residual disease suppressive qualities for this root rot disease.

Foliar brown spot symptoms were first observed the week of July 9 in only 21 of the 70 rows designated for disease assessment. Symptomatic foliage never exceeded 10% of the total canopy during the season, and with infrequent rainfall and the lack of heavy rain during the months of July and August, severity remained low. Plants exhibiting severe root rot disease possessed fewer brown spot symptoms, but this relationship was weak ($R^2 = 10\%$, $P < 0.01$).

The effect of PMR amendments on the cumulative amount of brown spot disease (area under the disease progress curve) varied this year (Fig. 1). Re-application with the low rate of either PMR compost had no effect on disease severity. On the whole, however, re-application with fresh material worsened ($P < 0.01$) disease symptoms compared to their un-amended counterpart (residual effect of previous 4 yrs). In 1999, our 1st snap bean year and 2nd amendment year, we found that both rates of PMRC significantly suppressed foliar brown spot. This year, our 5th year of amending our plots, the reverse occurred. We are currently looking into the possible contributor to enhanced foliar brown spot symptoms in 2002.

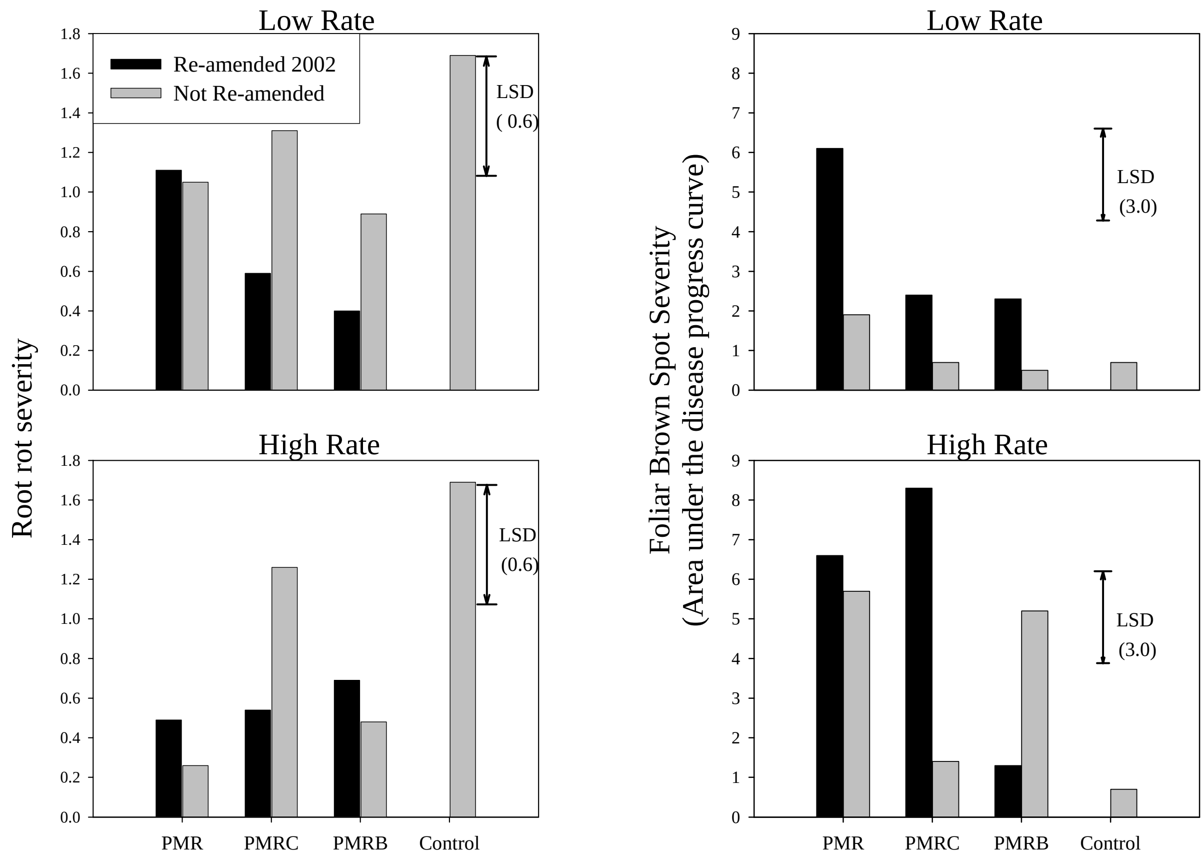

Fig. 1. Re-application and residual effects of fresh (PMR) and composted (PMRC, PMRB) on naturally occurring diseases on snap bean in our Hancock split-plots in 2002. LSD = least significant difference at $P < 0.05$.

<u>Snap Bean Yield:</u>

Root rot reduced yields considerably in the non-amended control plots, and as a result, produced yields significantly lower than all PMR-amended plots. In plots that received fresh material in 2002 (Fig. 2A), yields increased 56 – 83% ($P < 0.05$) over the control treatment. As we measured in our 1999 snap bean year, re-application of the high rate of raw PMR produced the greatest yields. With the exception of the low rate of PMR, amendments had residual yield-promoting effects (Fig. 2B). Re-amending with the low rate of PMR increased yield 38% compared to its unamended counterpart. Both composts produced yield-enhancing effects long after the soil received the amendment from the previous season. Class 5 bean yields (canning beans) were greatest in the high rate of re-applied raw PMR, while the lowest yielding treatments were the non-amended controls and the low rates of PMR and PMRC. Re-application of the two composts increased the proportion of beans in the canning size category of bean.

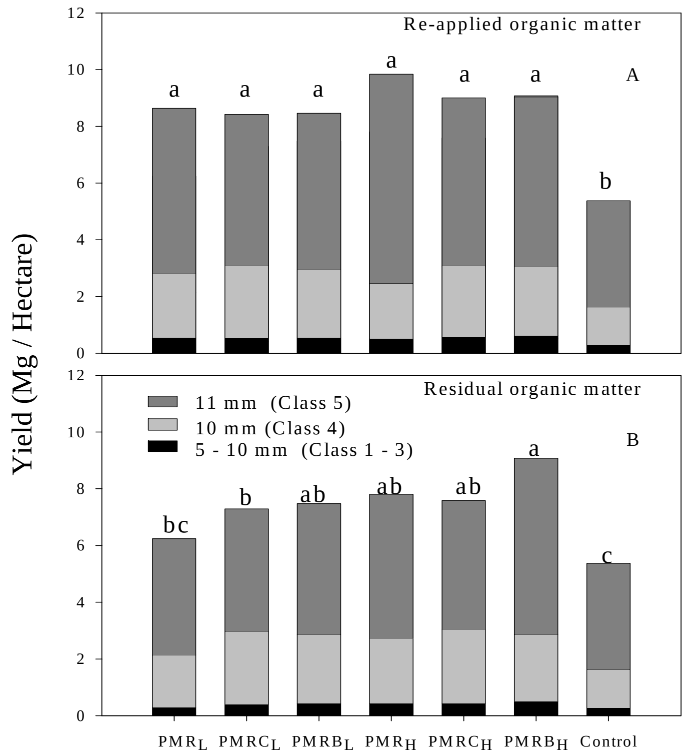

Fig. 2. Re-application (A) and residual (B) effects of raw PMR and composted PMR (PMRC, PMRB) on snap bean yield in our Hancock split-plots in 2002. For each panel of bars (A or B), bars headed by a different letter are significantly different at $P < 0.05$.

Progress to Date:

Our research with PMR and PMR composts informs us that both total (Fig. 3) and active-fraction soil carbon (organic matter) are increasing with each annual addition of the amendments. We measured 5 - 45% increases in plant available water (Foley and Cooperband, 2002; Newman et. al., 2001). Increases in plant available water could be explained in part by the increases in total soil C (significant positive linear relationship between total carbon and plant available water) with the composted PMR treatments producing the greatest increases in the five years of study. After two years of annual additions, snap bean and oats (cover crop) responded positively to all PMR amendments (Foley, 2000). Increased moisture holding capacity of amended soils likely had a positive effect on utilization of available N. After three years of annual amendments, PMRB and PMRC composts have increased organic soil nitrogen in the top 15 cm (6") and they continued to do so in 2002. While this suggests that these treatments are building a stable pool of nitrogen, there is still likelihood of post-crop harvest N mineralization, and we recommend fall cover crops (rye, oats) to trap available nitrate.

We discovered that after four years of annually applying PMR amendments to sandy soil, variability in treatment effects on total soil C decreased (Fig. 3) and the temporal patterns followed by each treatment, including the non-amended control, were similar to eachother. For example, in 2000, total soil C in the PMRB treatment decreased relatively rapidly during that season, while the carbon content steadily increased in soils amended with the compost without bark (PMRC). In 2001 and 2002, in-season patterns among treatments were more similar. The decreased variability in treatment effects on the content of organic matter in our plots is likely due to 1) increased homogeneity of material added to soil and the cultural practices used and/or 2) stabilization of the soil microbial community responsible for decomposition of organic matter.

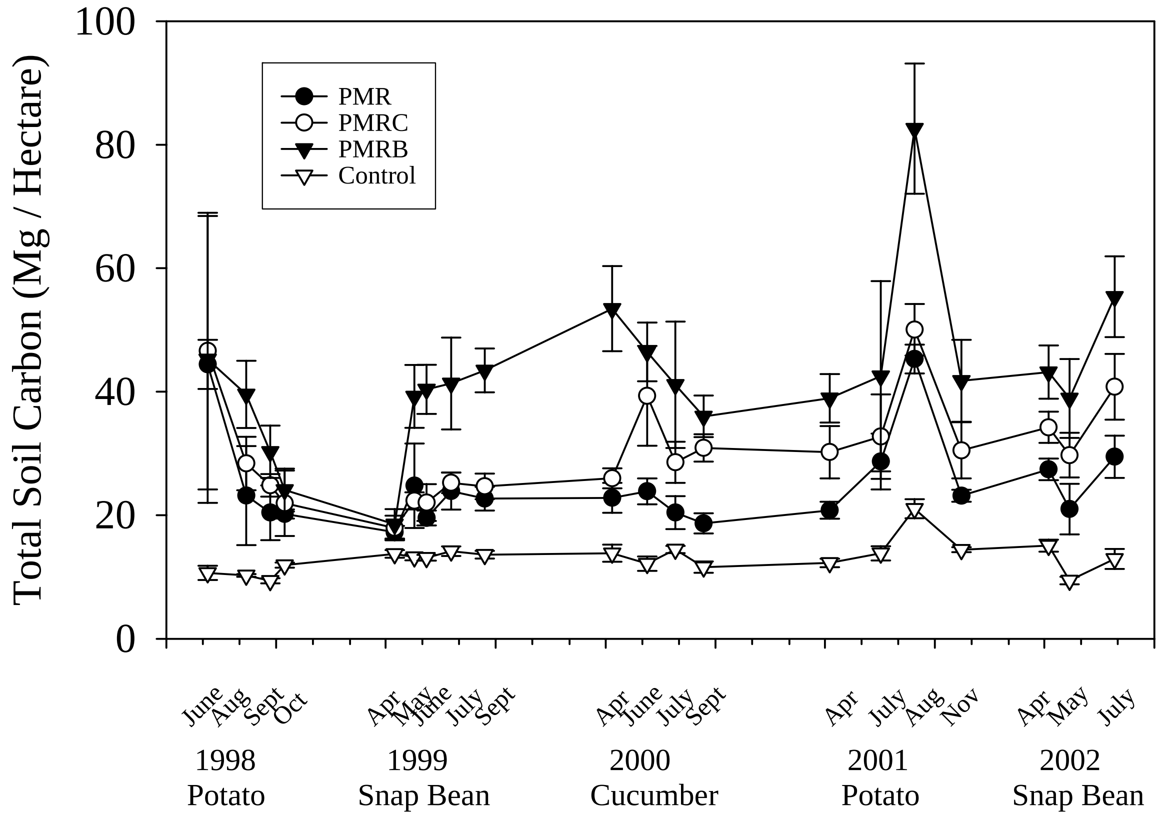

Fig. 3. Total soil carbon over 5 years for high rates of PMR and PMR composts.

Disease suppression varies with the type of PMR amendment, pathogen, and host. In our first year of study (potato; 1998), raw and composted PMR amendments significantly influenced storage and foliar disease incidence. All PMR amendments produced fewer tubers with Pythium leak (storage rot) relative to the no-amendment control. However, early blight incidence was significantly higher in raw and composted PMR plots as compared to non-amended plots, which was presumably due to nitrogen deficiency in amended treatments. In the second year (snap bean; 1999), incidence of aerial *Pythium* was reduced dramatically in fresh and composted PMR treatments (Stone et al., 2002). Severity of pod brown spot was suppressed significantly in the PMR compost treatments in 1999, but not in 2002. In 2002, all amendments controlled root rot. Only the high rate of fresh PMR resulted in enhanced crop yield in 1999, but by the 5th year of amendment, all amendments enhanced snap bean yield. In the third year (cucumber; 2000), the high rate of PMR compost without bark showed significant suppression of another foliar disease, angular leaf spot.

Weather conditions in 2001 (potato season) were optimal for potato early dying (PED) disease, and there were significant amendment effects on PED severity (Rotenberg and Cooperband, 2001; Wisconsin's Annual Potato Meeting 2002). Over the growing season, both rates of the two PMR composts (with or without bark) produced 1.5-2 times greater PED disease than the no-amendment control. Superficial and pitted scab incidence was highest (but not statistically significant) in the high rate of fresh PMR compared to all other treatments. Despite the higher PED severity in plots amended with the high rate of PMR, there was a significantly higher yield of Grade A-potatoes in this treatment as compared to the no-amendment control. Overall, we find that PMR and PMR composts hold promise for alternative management of vegetable diseases, while improving soil quality in Wisconsin's Central Sands.

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