

# **Using Paper Mill Sludge and Compost in Potato Production: First Year Effects on Soil Quality and Crop Production**

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## **Introduction and Research Objectives**

Use of organic by-products as soil amendments in agricultural production exemplifies a strategy for converting wastes to resources. Paper mill sludge is one of the largest underutilized organic by-products in Wisconsin. Paper mill sludge (PS) generation in Wisconsin increases approximately 5% per year, and 70% of all PS generated currently (740,000 dry tons) is land filled (Wisconsin Paper Council, 1998; pers. comm.). As landfill options decline for both economic and environmental reasons, the paper industry is shifting focus to beneficial reuse (J. Katers, UWEX Solid and Hazardous Waste Educ. Ctr., 1998; pers. comm.). At present, only 12% of PS generated (88,000 dry tons) is land spread; however, there is growing interest in using PS as a soil amendment. Use of PS or PS compost in annual crop production systems holds promise from a soil quality perspective, particularly in coarse-textured sandy soils where increases in organic matter content can improve soil chemical, biological and physical properties.

The Central Sands is Wisconsin's foremost vegetable producing region. It is characterized by intensive, irrigated crop production on sandy soils underlain by increasingly contaminated aquifers. Vegetable producers currently are faced with declining crop prices, higher input costs, and increasing pressures to reduce pesticide and commercial fertilizer use. Mounting concern about environmental contamination from vegetable production in the Central Sands has spurred interest in alternative crop management systems. The Wisconsin Potato Vegetable Grower's Association (WPVGA) has identified soil quality improvement as one of their central goals in sustaining vegetable production while minimizing negative environmental impacts.

Central Wisconsin is also home to large-scale paper production, and hence, generation of paper mill sludge. For example, the Consolidated Paper Company in Wisconsin Rapids produces approximately 46,000 wet tons of PS annually. While much of their PS is land spread on cropland as Consagro®, other paper mills in the region largely rely on landfills for disposal. There is growing interest in using PS in vegetable crop production in the Central Sands. However, many vegetable processing plants will not accept crops grown with PS

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because of concern for possible crop contamination (organic chemical residues and trace metals). Recent analyses of Consogro® have demonstrated undetectable levels of chlorinated compounds. If we can quantify the short and long-term soil and crop benefits associated with PS use and allay concerns about potential contamination from PS, perhaps both vegetable producers and processors will recognize its value and promote more widespread land use.

Previous evaluations of PS use in crop production have focused on short-term improvements in soil fertility like nutrient availability and crop yield. Several studies have been conducted since the early 1980's (Huettl, 1982; Benzel, 1986, Shimek et al., 1988; Bowen et al., 1995). John Peters (UW-Marshfield Research Station Soil Testing Lab, pers. comm.) study (1986-present) used PS from Consolidated Paper (Consogro®) in a potato-sweet corn rotation to supply either all or 50% of crop N needs. Results showed that approximately 25% of the total N content of PS became available over the growing season from PS with a low C:N ratio (approximately 20:1). Bowen et al.'s (1995) study using PS and PS compost in potato production showed that PS-amended potato plots could produce yields equivalent to or higher than those receiving 200 lbs. N/acre of commercial fertilizer. While these studies clearly demonstrated that PS amendments could enhance crop yield and marketability relative to conventionally fertilized controls, they did not fully investigate nutrient mineralization throughout the growing season or PS effects on other soil properties.

In addition to fertilizer value, organic amendments also improve properties such as bulk density, water holding capacity, soil structure and cation exchange capacity (Herrick and Wander, 1997). Recent studies have demonstrated improvements in soil properties using a variety of composted materials. Steffen et al. (1995) showed that vegetable crops could be grown for three years consecutively from a single, high application of spent-mushroom-substrate compost. Maynard (1997) attained higher yields for tomatoes and eggplant in fields amended with yard waste (leaf) compost compared to fields receiving commercial fertilizer or undecomposed leaves. The most dramatic impact of compost application was the increase in pH (from acid to near neutral) and soil organic matter (from 3.6 to 5%). The long-term effects of PS and PS compost on soil chemical and physical properties have not been well documented, particularly on sandy soils. Composting PS is a potential management strategy during periods when land spreading of raw PS is not possible or higher application rates are desired.

The overall objective of our ongoing research project is to evaluate the short and long term benefits of amending sandy soils with paper mill sludge and PS composts in a vegetable rotation in Wisconsin's Central Sands. Specifically, we are investigating the effects of PS and PS compost (PSC) amendments on soil quality, including:

- a) In-season nutrient (N, P, K, Ca, Mg and micronutrients) availability and crop use efficiency
- b) soil physical properties (moisture content, soil temperature, water holding capacity and aggregate stability)
- c) soil chemical properties (cation exchange capacity, total and labile organic C, pH, electrical conductivity)
- d) soil biological properties including parasitic and beneficial nematode populations and microbial biomass
- e) Disease suppression of major soil-borne diseases affecting each crop in the rotation.

We also plan to relate changes in soil quality to crop disease incidence, plant growth, mineral nutrition and crop yield. Ultimately, we hope to translate the potential benefits of using organic amendments in vegetable production in the Central Sands into economic savings. The results presented in this article represent selected data from the first year of a six-year study.

### **Research Design and Measurements**

We initiated a field trial at the UW Hancock Agricultural Research Station in March 1998. The predominant soil type at the Hancock field station is Plainfield loamy sand. The experimental design is a randomized complete block with amendment type/rate as the main effect (total of 9 treatments). These treatments are replicated five times in plots 15' X25'. Organic materials were amended to field plots in late April 1998. The amendments include 1) raw PS (from Consolidated Paper, Inc.), 2) stabilized PS (1 yr. old composted PS from Rhinelander-Oneida Co. Landfill; no bulking agent) 3) a PS/bark mix compost (commercially available product from Michigan), 4) dark peat (predictably non-biologically active organic material) and 5) no organic amendment. Organic amendments were applied evenly over each plot at two rates. Raw PS was applied at 50% and 100% of potato N requirements (estimated to be 200 lbs. N/acre on sandy soils, Kelling and Heroe, 1993).

We measured total N content of raw PS prior to land application and assumed that 25% of TN would be available in 1998 (J. Peters, pers. comm.). Stabilized PS (PSC), PSC-Bark and peat were applied on an equivalent dry weight basis of the 100% raw PS rate and 2X the 100% rate. Peat plots and no organic amendment control plots received a split application of 200 lbs. N/acre (100 lbs. N/acre at emergence and 100 lbs. N/acre at hilling; Kelling and Hero, 1993). All plots received 600 lbs./acre of 6-24-24 starter fertilizer. Certain organic amendment plots received supplemental N during the growing season when potatoes exhibited signs of N deficiency.

Each plot was planted with five rows of Russet Burbank seed pieces on 3' centers at 12" spacing. Weed and insect pests were managed using conventional best management practices by the Hancock Agricultural Research Station staff. All treatments received fungicide treatments to provide a moderate level of control of early and late blight (Stevenson and James, 1997). This

strategy controlled disease but enabled us to detect any enhancement of disease control due to organic amendments. Plots were not fumigated for control of Verticillium wilt.

#### Soil Chemical and Physical Measurements

*Soil chemical analysis:* Available N and P were evaluated weekly using ion exchange membranes inserted vertically into the top 6 inches of the soil (Cooperband and Logan, 1994). Results are presented for nitrogen only as mg of either ammonium or nitrate N/cm<sup>2</sup> of resin membrane (an relative measure of available N). Total soil C was determined via combustion on bulk soil samples using a CHN Analyzer.

*Soil physical measurements:* Soil moisture content was measured gravimetrically in the top 6 inches on a weekly basis. Moisture retention curves were determined using a low range system (0 – 20 J/kg) on all treatments in three blocks. The water retention data was used to estimate the volumetric water content at 33 J/kg and 1500 J/kg (Campbell 1985). The difference of volumetric water content at these two potentials was taken as plant-available water.

#### Crop Yield

*Crop Yield and Quality:* 50 row feet from each plot were harvested and graded into US #1 (A), undersize (B), and cull categories. An optical size grader was used to sort the US#1 potatoes into <4 oz, 4-6 oz, 6-10 oz, 10-13 oz, 13-16 oz, and >16 oz

### **Results**

Soil Physical Measurements Soil water content varied substantially among treatments and over the growing season (Figure 1). Within a given application rate, plots that were amended with the two composted PS materials (stabilized and composted with bark) and peat had greater soil moisture contents than the raw PS. Averaged over the growing season, there were no significant differences in water content among amendments at the low rates; however, there were significant differences among amendments at high rates. In addition, plots amended with organic materials statistically increased the volumetric moisture content 25% - 67%.

#### Moisture Retention Curves and Plant-Available Water

Over the low tension range (0 – 20J/kg), high rates of peat and PSC Bark increased the soil's volumetric water content relative to the no-amendment control. Higher volumetric water content from saturation to near field capacity suggests total porosity has been increased. This would translate to higher water holding capacity compared to the no-amendment control.

All amendments, except the low rate of raw PS, increased plant-available water relative to the control (Figure 2). Peat significantly increased plant-available water over the no-amended control. PSC Bark (high) significantly increased plant-available water compared to PS (low) and the control. Overall, there was

33%-150% more plant-available water in high rate treatments compared to the control. However, the amount of plant available water was nearly equal for both rates of PSC.

#### Analysis of Total Soil Carbon

Total carbon in high amendment rate treatments was approximately twice the amount of total carbon in low amendment rate treatments (Table 1). There was roughly a 50-60% decrease in total carbon one year after amendments were applied. The exceptions were low PS and high peat, which lost 7% and 73%, respectively. Despite proportionately greater losses of total carbon from high rate treatments, there was still significantly more carbon in high rates than in low rates after one year of decomposition.

#### Plant Available Water and Total Carbon Relations

There was a strong positive linear relationship between total soil carbon and plant-available water one year after amendments were applied (Figure 3). Peat and the high rate of PSC Bark tended to have the highest amounts of total carbon and also held the most plant-available water. The low rate of peat also shares this relationship although not as consistently.

#### Ammonium Nitrogen Dynamics

For the first post-amendment measurement (06/09/98), plots amended at low rates generally had more available  $\text{NH}_4\text{-N}$  than those amended at high rates (data not shown). This suggests greater nitrogen immobilization at high amendment rates. Post-fertilizer application measurements (09/01/98-11/15/98) indicated that  $\text{NH}_4\text{-N}$  concentrations decreased to near zero for the remainder of the growing and post-harvest periods. Statistical analysis of available  $\text{NH}_4\text{-N}$  changes over the growing season yielded no significant differences among the treatments from late spring to late fall of 1998.

Nitrate Nitrogen Dynamics Early growing-season measurements of available  $\text{NO}_3\text{-N}$  were dominated by commercial fertilizer N additions (data not shown). Late growing season/ post-harvest (09/01/98-11/15/98) measurements of available nitrate N, assumed to exclude the effect of nitrogen fertilizer, showed increased  $\text{NO}_3\text{-N}$  availability in all amended treatments relative to the control (Figure 4). Statistical analysis of amendment/rate effects over time yielded significant differences among the treatments ( $P < 0.0001$ ). On 11/13/98  $\text{NO}_3\text{-N}$  concentrations measured in high rates of PSC, PSC Bark and PS amended treatments were significantly greater than the control ( $P < 0.0001$ ,  $P < 0.017$ , and  $P < 0.0005$ , respectively).

#### Potato Yield and Quality

There was a significant effect of amendment type but not application rate on both potato yield and quality measurements. The grade A and total yields for plots amended with PS, PSC and PSC Bark were similar to yields obtained from the no-amendment control (Table 2). There was no significant amendment type

effect on the yield of “B” quality potatoes. The plots amended with the PSC-Bark produced significantly higher numbers of culls, but this did not adversely affect the total yield. The low yields in peat are likely the result of stunted growth from low soil pH conditions. These results suggest that the addition of paper mill sludge and PS compost at high and low rates produced potato yields and quality comparable to those grown with conventional potato production practices.

### **Summary of Preliminary Findings**

The results presented here represent the first year of a six-year study of two complete three-year rotation cycles (potato/snap bean/cucumber). Amendments will be applied each year and the long-term impacts of the amendments on soil quality and crop productivity will be assessed. These first year results suggest that addition of PS or composted PS at low to high rates produces yields and potato quality comparable to potatoes grown with conventional practices.

After one year of amendment, soil moisture content increased by 25%-67% above the no-amendment control. Overall, amendments increased water holding capacity and plant-available water by 33%-150% above the no-amendment control. First-year amendments increased the soil's total carbon content from 23%-180% relative to the control.

There was a significant increase in available NO<sub>3</sub>-N in plots amended at high rates of PSC, PSC Bark and PS after harvest. Although we did not measure nitrate leaching directly, we speculate that most of this available NO<sub>3</sub>-N was lost via leaching over winter. As such, we may have to consider use of a fall cover crop to minimize nitrogen leaching.

### **Implications and Plans for the Future**

Few studies have investigated intermediate to long-term effects of sequential organic amendments on soil properties and plant productivity. This work should further our understanding of nutrient availability from raw and composted PS so that we can make better recommendations about rates and application timing for optimal crop benefit. We are also quantifying soil physical benefits of PS and PSC applications to sandy soils, namely improvements in soil water content, water holding capacity and aggregation. These benefits should reduce irrigation requirements and frequency, increase nutrient use efficiency, and potentially reduce N leaching to ground water. Improving aggregate stability should reduce potential for wind erosion.

The effect of PS/PSC amendments on potato disease incidence has never been investigated. Reduced disease incidence, should it occur, could result in reduced use of pesticides, increased yields, and higher economic returns to growers. As we continue to collect data on soil properties, disease incidence and crop production, we will attempt to quantify the economic benefits associated with improvements in soil physical and biological properties and reductions in

environmental contamination. All of these environmental and agronomic issues must be addressed and alternative management scenarios presented if vegetable production is to remain economically viable in the Central Sands. Quantification of these expected benefits and resultant management recommendations should also provide greater justification for using PS in crop production. Use of PS and/or PS compost on vegetable acreage in the Central Sands could significantly reduce the amount of PS currently land filled.

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