CROP AND SOIL RESPONSES TO FIBROUS PAPER MILL SLUDGE

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The production of pulp and paper is a major industry in Wisconsin with many mills located along the Wisconsin River valley in north central Wisconsin. One of the leaders in this industry is Stora Enso North America (formerly Consolidated Papers, Inc.) with their state headquarters in Wisconsin Rapids. As a consequence of producing a variety of finished paper products, a significant amount of byproduct material is generated. Prior to the mid-1980's most of this byproduct material was land-filled. Consolidated Papers Inc., began a research program in the 1970's to look at various land spreading options, largely focusing on the sandy textured soils which are predominant in the area. The development of a land spreading program has the dual benefit of reducing the need for costly landfill space and recycle valuable nutrients and organic matter into local agricultural fields. This will have a positive economic and environmental impact on the industry, their clients and the community.

Earlier studies of the application of ConsoGro sludge to agricultural land showed the material to be an excellent source of organic matter and nitrogen for soils planted to vegetable crops on the sandy textured soils of Central Wisconsin (Peters, 1994). In the mid-1980's, Consolidated Papers Inc. received approval to begin a land spreading program which continues today. The material, called ConsoGro, is largely applied to irrigated sandy textured soils in central Wisconsin. Throughout the years, research has evolved to look at various aspects of the land spreading program and study a number of alternative practices. One of the options which has been studied is the application of ConsoGro to supply either all or one-half of the required available N for crop production. Assay crops used in these studies include field corn, soybeans and typical commercial vegetable crops grown in the area such as sweet corn, potatoes, and snapbeans. Other studies have focused on the impact of a varying C:N ratio on the value of the sludge as a soil amendment using field corn as the test crop. This paper summarizes these activities over the past ten year period.

Materials and Methods

In 1993, plots were established on a privately owned field near Plover, in the Portage County town of Grant. Two main plots, each 60ft. x 60ft., were established with permanent markers. At that time, soil samples were taken to measure background fertility levels. The general fertility status of this Plainfield series soil was found to be suitable for typical vegetable crops grown in the central Wisconsin area. Past work indicated that approximately 25% of the total N in ConsoGro sludge is available in the year of application (Peters, 1989). Based on this information, an application rate was calculated to provide approximately 200 lbs available N/a. ConsoGro was spread using a small skid-steer loader and incorporated to a depth of six inches using a rototiller. A similar

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approach to applying and incorporating sludge was used in all subsequent years of the study. In 1993, potatoes, sweet corn, and snapbeans were planted as assay crops. In 1994, the study was repeated at this same location with very few modifications.

As there can be some variability in the makeup of the fibrous sludge depending on the process at the mill, there was some question as to how these differences in C:N ratio might impact the performance of the sludge when land applied. To help answer this question, another study was designed in 1994 to look at the performance of sludge materials with a range of C:N ratios. Field corn was grown as the test crop and the three sludge materials with varying C:N ratios were compared with commercial N fertilizer. Plant tissue analysis was conducted and silage and grain yields were measured. This trial continued in 1995, with the residual impact of earlier sludge application being monitored. Also in 1995, a new study was begun to compare the performance of ConsoGro sludge with commercial N fertilizer as the sole sources of required N and a third treatment where one-half of the required N was provided by each source. This comparison of all N from sludge or commercial N with a 50:50 treatment continued with a number of modifications through 2002. In 1999, a second main effect was added to the study and a new plot site established at a third location. This new study included an evaluation of the effect of varying the frequency of sludge application (annual, biannual, and every third year). Another modification was the substitution of soybeans for snapbeans as an assay crop. This was done to eliminate the potential variability in maturity of snapbeans based on the N source. This snapbean maturity issue was studied in another trial which was run in 2002 and 2003, but is not reported in this paper.

Table 1. Description of treatments.

Treatment	Description
100% ConsoGro	Full rate of N from ConsoGro sludge to meet requirements of crop
Commercial N control	Commercial fertilizer to meet N requirements of crop
50:50	One-half rate of N from commercial fertilizer, one-half from ConsoGro sludge to meet requirements of crop

The crop nitrogen requirements used in the study were field corn-200 lb/a, sweet corn-150 lb/a, snapbeans-60 lb/a and potatoes-200 lb/a. These rates were based on University of Wisconsin recommendations (Kelling et al, 1997).

In most years, plant tissue samples were taken at mid-season to monitor plant nutrient status and again at harvest to measure total uptake of nutrients. Soil samples were taken at the beginning (pre-treatment) and end (post-harvest) of every growing season.

All analyses were performed by the UWEX Soil and Plant Analysis Laboratories at Madison and Marshfield using methods described by Schulte, et al (1987).

Results and Discussion

Previous studies involving sludge application show that the application of ConsoGro results in the improvement of soil water and nutrient holding ability. ConsoGro was also shown to generally improve soil physical properties. However, as with all organic soil amendments, it takes some time for this impact to fully evidence itself through soil test parameters (Peters, 1994).

Complete soil analyses were performed before treatment and following harvest in each of the years of this long term study. In general, the application of ConsoGro sludge resulted in an increase in soil organic matter, pH, TN (total nitrogen), exchangeable Ca, and available SO_4-S. Conversely, it appears that soil test K is somewhat reduced when sludge is applied. This is likely the result of ion competition for the soil exchange sites from the Ca added with the sludge. An example of this data can be found in table 2, where results from the first year of treatments at two different locations can be found. During the ten years of the studies being reported here, there were some changes made to the paper making process which resulted in an increased use of lime as a substitute for other materials such as clay. Therefore, the application of sludge in the more recent years has had an effect of raising soil pH. Little consistent impact can be seen on other soil test parameters monitored.

Table 2. Effect of sludge treatment on pre-plant and post-harvest soil test parameters.

	1994		2000	
Soil test parameter	Pre-plant	Post-harvest	Pre-plant	Post-harvest
pH	6.4	6.2	6.1	6.5
OM	1.0	1.4	1.7	18
K	131	115	176	150
Ca	358	623	477	877
SO_4-S	3.4	8.1	3.9	4.8
TN	300	500	328	748

1994 and 2000 were the first years of application at two different study locations.

In five of the ten years, field corn was grown in these studies. In the five years, when the N was supplied by all ConsoGro sludge, field corn grain yields averaged about 8% higher than when only commercial N was used as the N source (Figure 1). Since the soils in this area are very sandy (approximately 1.0% OM), at least some of this yield advantage is likely due to the improved physical properties of the soil such as increased water holding capacity. Long term soil test data indicates that soil OM levels are enhanced with periodic sludge applications (Table 2). Similarly, the dry matter yield of corn as silage was also enhanced by the use of sludge as an N source (Figure 2). Yields were about 12% higher when sludge provided the N than where commercial N was used. Results from the last two years of the study which included the 50:50 treatment, show that yield were considerably higher than in most earlier years, but there were much smaller differences between treatments. Cool weather early in the 2002 growing season appeared to result in delayed mineralization of the sludge as is also seen with dairy manure under similar conditions. This resulted in somewhat lower corn grain yields for the all N from sludge treatment. Mid-season tissue analysis data from the 2002 field corn confirms this. Tissue N levels were 3.5% for the commercial N control, 2.8% for the 50:50 treatment and 2.3% for the all N from sludge treatment, which is below the sufficiency level of 2.5%.

With some exceptions, sweet corn also responded favorably to ConsoGro sludge application (Figure 3). The nine year average indicates a 6% yield advantage of sludge amended plots over those where only commercial N was used. In looking at the seven years when all three N treatments were in place, yield differences between treatments were quite minimal.

Red Norland potatoes were grown as a test crop in most years of the study. In general, potato yields were significantly improved with the addition of ConsoGro to the soil as an N source and a source of organic matter. Yields were increased by about 19% on the average over the nine years of the study (Figure 4). During the seven years where the 50:50 treatment was used, potato yields averaged slightly more with this 50:50 treatment than when only sludge was applied (272 vs 267 cwt/a). In three years, white potatoes were grown as well as the traditional red Norlands. Yield responses for the white varieties were even greater than the reds with the 50:50 treatment averaging 317 cwt/a, all sludge 269 cwt/a and commercial N at 229 cwt/a (Figure 5). In looking at the data from potato grading and quality evaluation, there was little difference in the grade and disease evaluations when treatments are compared (data not shown).

Snapbean yields were clearly enhanced by the application of the N in the form of ConsoGro sludge (Figure 6). The five year average yields were increased by 28% by using sludge to provide the crops 60 lb N requirement. The response of soybeans to the application of ConsoGro was more variable (Figure 7). In some years the benefit was minimal, whereas in other years there was a yield enhancement. Overall, the four year average yield indicates a 10% yield advantage of sludge as compared to commercial N.

Table 3. Effect of sludge treatment on mid-season sweet corn earleaf tissue mineral levels.

	1994		2000	
Tissue parameter	Comm. N	ConsoGro	Comm. N	ConsoGro
N	2.73	3.11	2.78	2.38
P	0.42	0.47	0.30	0.31
K	2.70	2.46	2.47	2.34
Ca	0.60	0.88	0.38	0.51
S	0.16	0.26	0.29	0.22

Tissue analysis was conducted in most years of these studies, with analyses performed on both mid-season and harvested product samples. A typical example of the mid-season results for sweet corn can be found in table 3. In some years, tissue N levels were higher where ConsoGro was the N source and in other years these levels were lower than where commercial N was used. Much of this variability can be attributed to the individual growing season and, in particular, to the early season temperatures. Colder than normal weather can result in delayed mineralization of N from organic sources such as ConsoGro. Tissue K levels were typically lower where sludge was applied and tissue Ca levels were higher. In years where NH_4SO_4 was used as the source of commercial N, tissue S levels were typically higher in the commercial N plots, but when S was not a component of the N source, sludge amended plots had higher tissue S levels than the commercial N control.

Summary

In this long-term study, several observations can be made. The application of ConsoGro generally resulted in somewhat of an increase in soil pH, organic matter, total nitrogen content, as well as soil test levels of Ca, and SO_4-S and a tendency to lower soil test K. Crops which were grown on plots where sludge had been applied performed quite favorably when compared to the commercial N control plots. On these sandy textured soils, much of the crop yield response can be attributed to enhanced soil physical properties such as improved water and nutrient holding capacity. In most years, there is also an advantage to at least a portion of the N coming from a "slow release" organic source such as this ConsoGro sludge. This reduces the susceptibility to potential leaching losses from major rainfall events. Tissue analysis data verified that in most cases, N availability

was equal or greater with sludge application as compared to commercial fertilizer with a few exceptions, such as when exceptionally cold weather occurs early in the growing season. In summary, the ConsoGro land spreading program has been a huge success with many benefits such as improved soil physical properties, providing N and other plant essential nutrients as well as reducing the need for landfill space.

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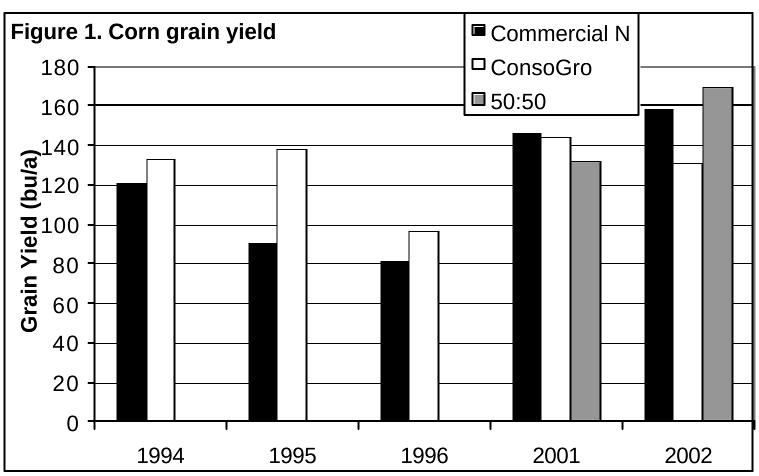
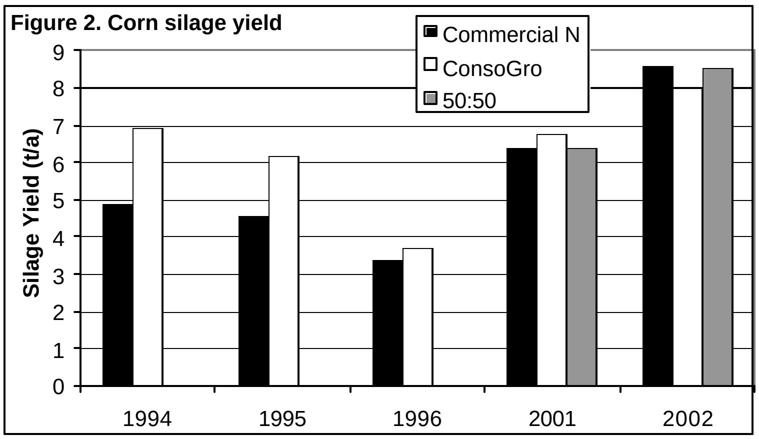
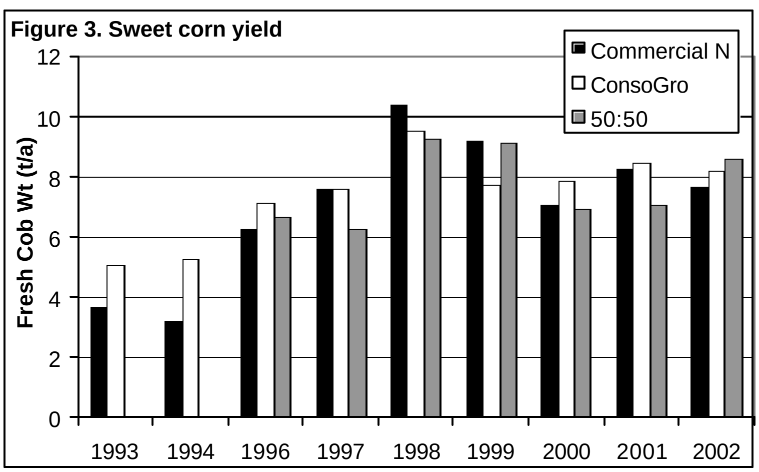
Figures



	5 yr ave	2 yr ave
	------- bu/a -------	
Commercial N	119.3	151.9
ConsoGro	128.6	137.8
50:50		151.1



	5 yr ave	2 yr ave
	------- t/a -------	
Commercial N	5.6	7.5
ConsoGro	6.3	7.4
50:50		7.5



	9 yr ave	7 yr ave
	------- t/a -------	
Commercial N	7.0	8.1
ConsoGro	7.4	8.1
50:50		7.7

	9 yr ave	7 yr ave
	------- cwt/a -------	
Commercial N	237	250
ConsoGro	282	267
50:50		272

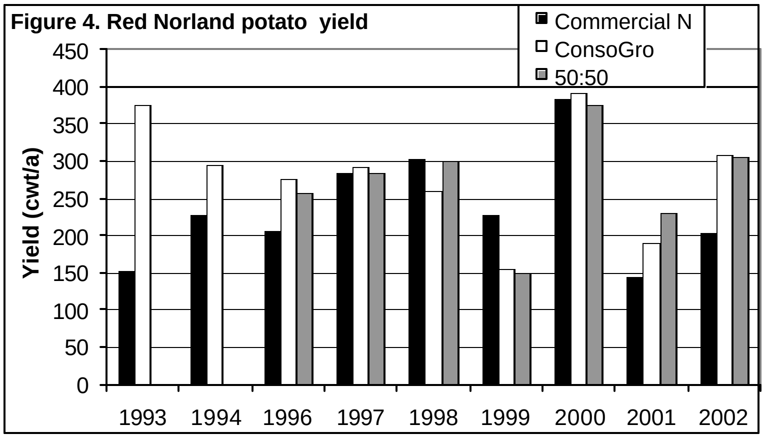


Figure 4. Red Norland potato yield

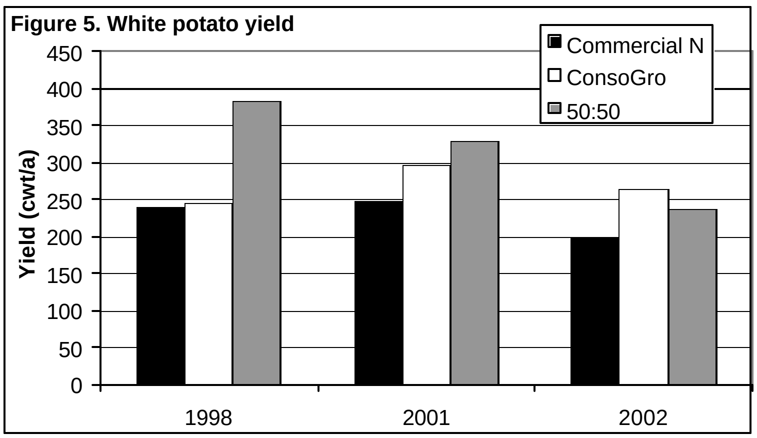


Figure 5. White potato yield

	3 yr ave
	cwt/a
Commercial N	229
ConsoGro	269
50:50	317

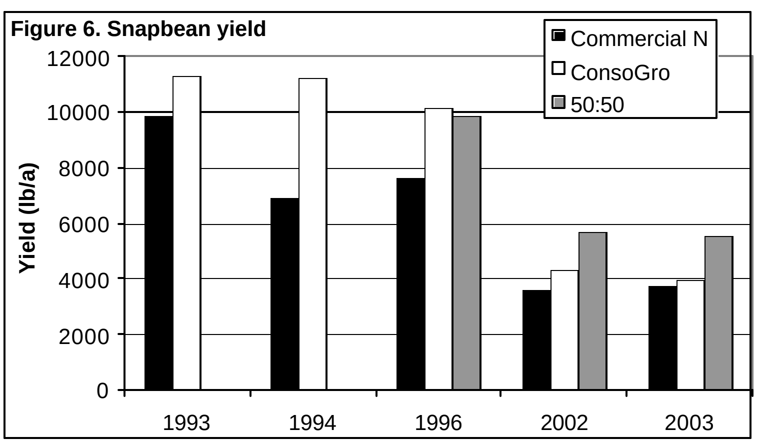


Figure 6. Snapbean yield

	5 yr ave	3 yr ave
	------- lb/a -------	
Commercial N	6351	5003
ConsoGro	8160	6131
50:50		7031

	4 yr ave
	bu/a
Commercial N	32.3
ConsoGro	35.5
50:50	34.4

Figure 7. Soybean yield