PART A: MANURE/SOIL/CROP INTERACTIONS
Soil Amendment Effects on Soil Quality, Nutrients and Yield

Introduction

The project objective was to compare effects of anaerobically digested and undigested manure sources on soil properties and crop yields at this farm. Field plots were fertilized with raw manure, digested manure or inorganic fertilizer and planted with silage corn. Soil variability was high at this site, but results suggest that the use of digested manure will produce yields equivalent to undigested manure or fertilizer, while simultaneously allowing the capture of bioenergy. Neither potentially mineralizable N, total C, total N, nor microbial biomass differed in soil samples taken from field plots treated with these amendments. However, laboratory incubations showed differences in N released at high application rates, with less N available from raw compared to digested or lagoon-stored manure during an 8 week incubation. Microbial respiration rates in the incubation experiment were higher in the raw manure treatment than for the other amendments at all application rates.

Materials and Methods

Field Experiment

The field plots for this research were located at Haubenschild Farms, Inc. in Princeton, Minnesota (T36N R26W). Three fields with different cropping histories were selected at different locations at the Haubenschild's farm. Each of these fields was located on Zimmerman Fine Sand (Mixed, frigid Lamellic Udipsamments); a soil with weak structure, high permeability, low organic matter content, and low exchangeable nitrogen and potassium. These soils formed in glacial outwash composed of well sorted sand and fine gravels. Layers of coarser and finer particles can differ greatly in thickness and depth, causing these soils to have high inherent variability. The three fields were: (1) the Appel field, which was in corn for two years prior to this study and had a history of manure application; (2) Bruce, which was a CRP field for the two years before this study and had no history of manure application within 30 years; and (3) the Lilac field which had been in alfalfa for the two previous years and had a history of manure application. Three different histories were chosen in order to compare amendment effects on areas which did or did not have previous manure application, or which had manure application in association with a leguminous crop. Each of these fields had 18 plots, 6.08 meters wide and 60.8 meters long (plots in the Appel field were restricted to 53.2 meters). There were three input treatments (digested manure, raw manure, inorganic fertilizer), two application frequencies (annual or biennial) and three replications per field.

The Bruce and the Lilac fields were established in 2001 and treatments were imposed again in 2002 and 2003 (Figs. 1 and 2).

Figure 1 2001-2003 Haubenschild Bruce Plot

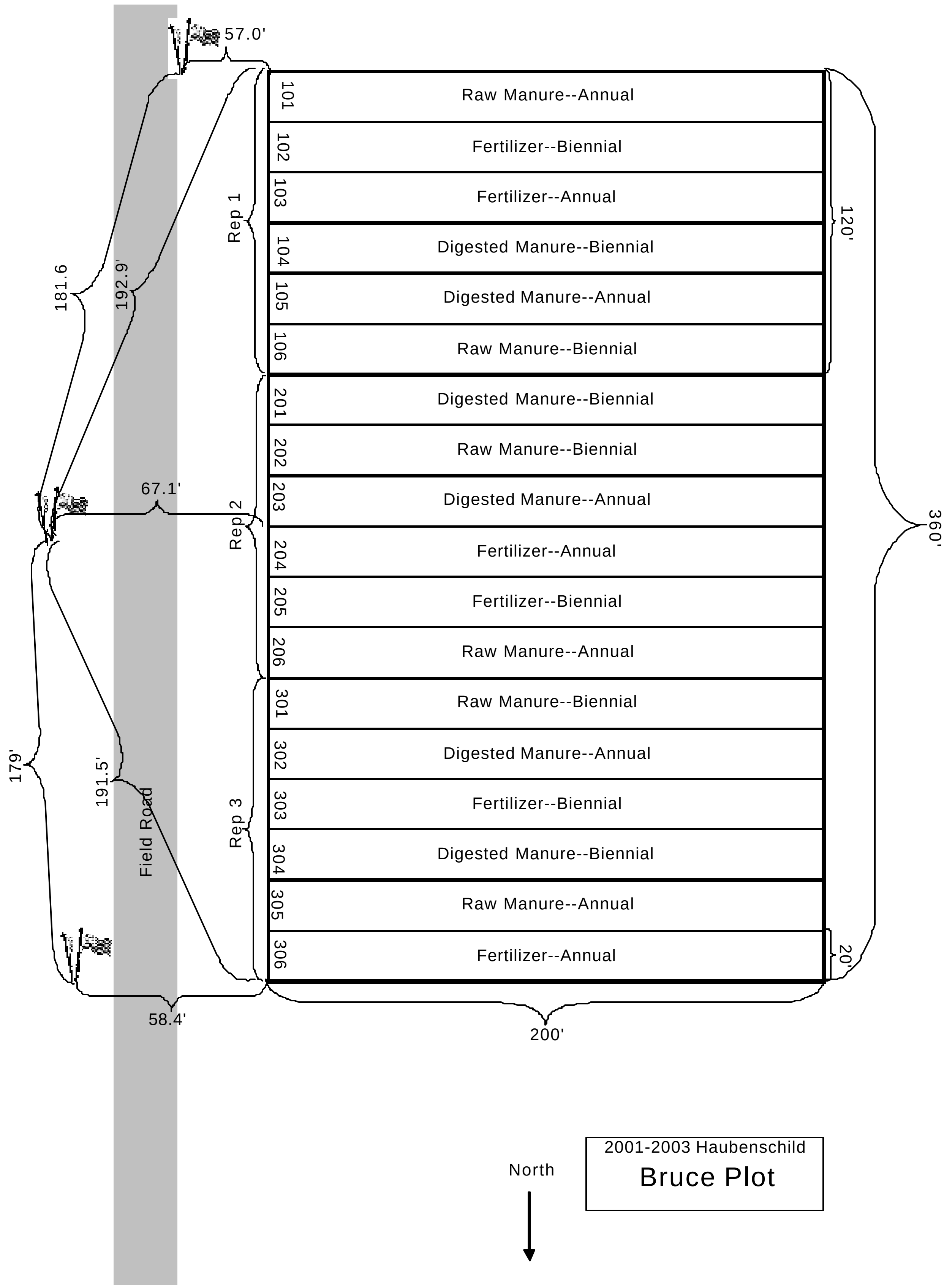


Figure 2 2001-2003 Haubenschild Lilac Plot

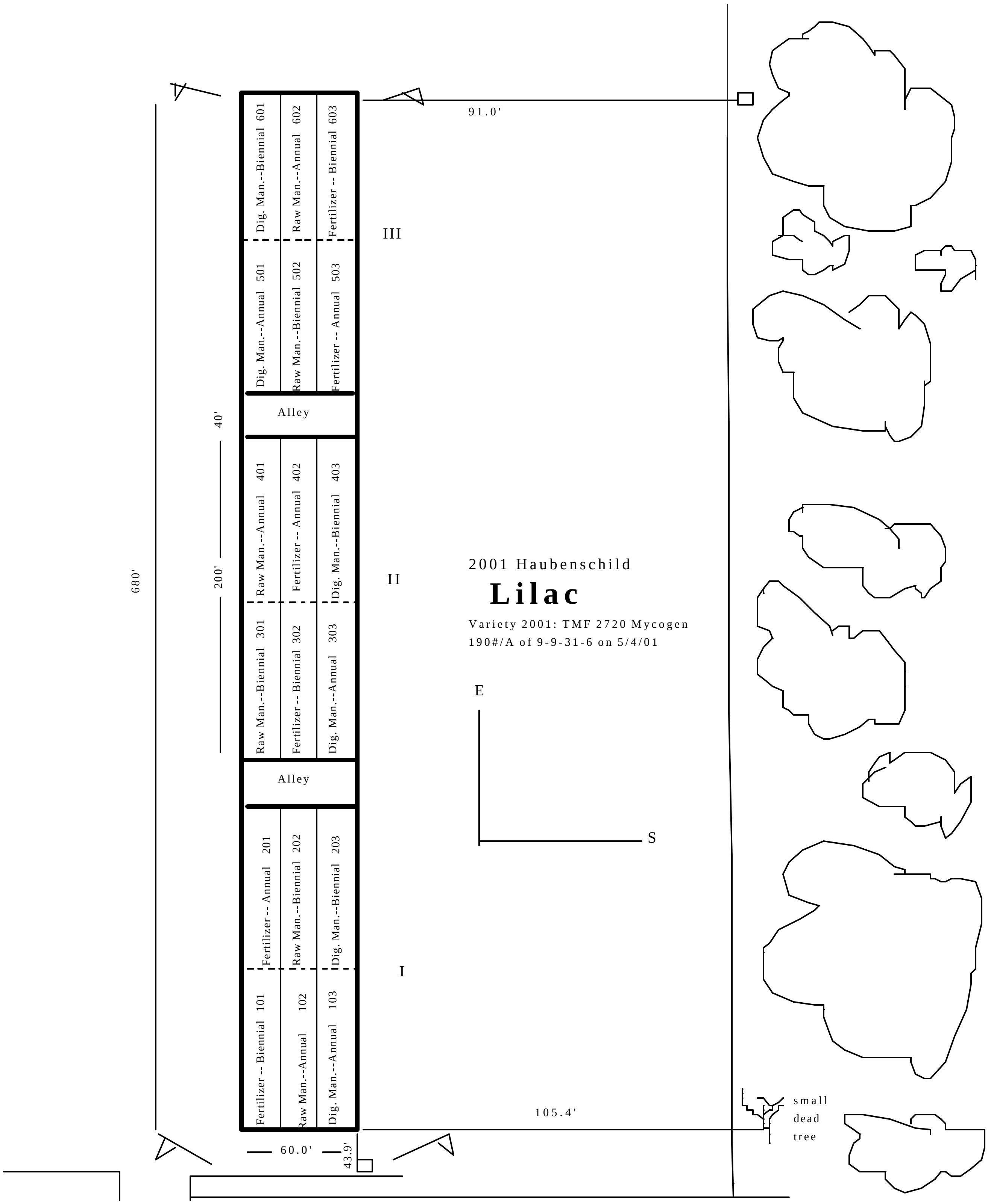


Figure 5 2002-2003 Haubenschild Appel Plot

In 2003, plot 206 in the Bruce field mistakenly received two types of inputs; that plot was not used for analysis in 2003. The Appel field was also established in 2001; but the entire plot area was accidentally fertilized with digested manure after the 2001 growing season. These plots had to be reestablished in the spring of 2002 in a different location with the same management history (Figs. 3 and 4).

Figure 3 2001 Haubenschild Appel Plot

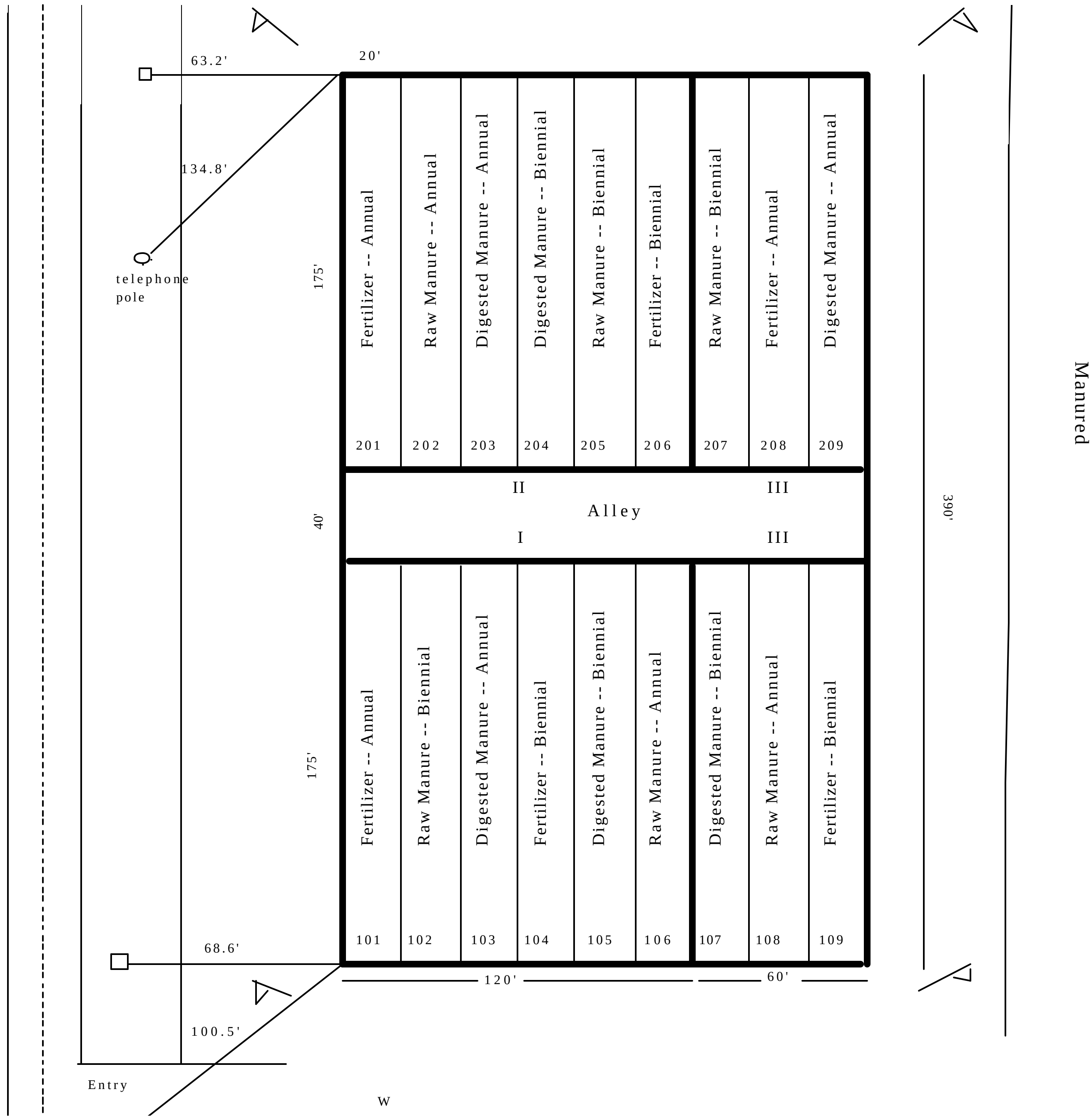
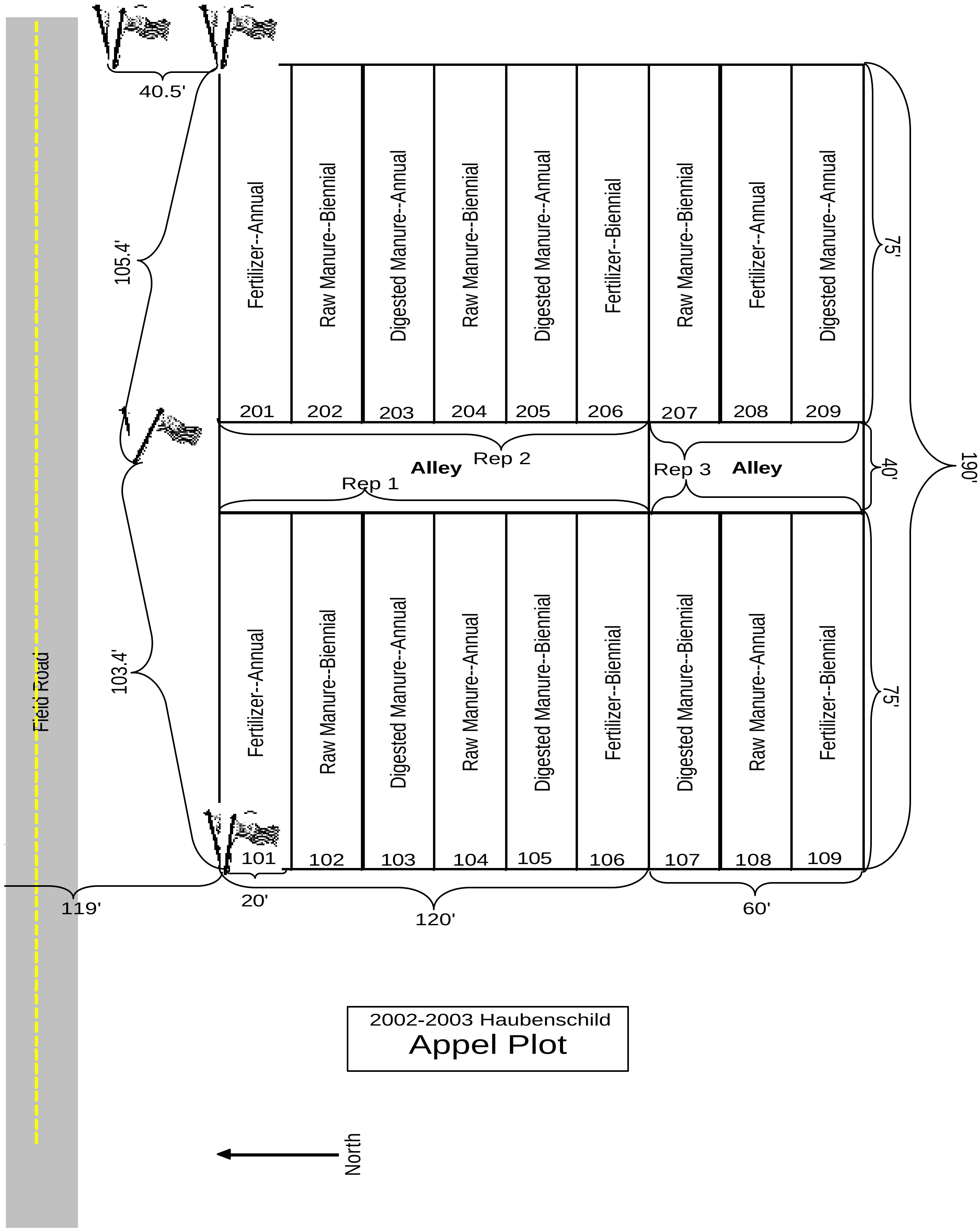


Figure 4 2002-2003 Haubenschild Appel Plot



The Appel field was therefore a year behind in receiving manure application and in the annual/biennial determination. In 2003, manure was applied differently than the 2002 map indicates to two of the plots. Plot 202 became raw manure – Annual, rather than raw manure – Biennial and plot 203 became digested manure – Biennial, rather than digested manure – Annual. Soil pH, nitrate, phosphorus (P), and potassium (K) baseline values were tested for all three fields on April 18, 2001 (Table 1).

Table 1. Soil Test Values by Study Site Prior to Fertilizer Treatment Application, Haubenschild Farm, Princeton, MN 2001

Field	pH[1]	Bray-P	Potassium	Nitrate
		mg/kg		
Appel	6.9	108	210	2.4
Bruce	6.1	42	98	2.8
Lilac	6.2	112	74	7.0

[1] pH, Bray- P, and potassium were sampled to a depth of 15cm; Nitrate was sampled to a depth of 60cm.

Manure and inorganic fertilizer were applied by sweep injection to a depth of 20cm, with 76cm spacing. The plots received a lower than recommended rate of application in order to avoid masking potential differences among the fertilizer treatments. On April 26, 2001 raw and digested manures were applied at 28m^3/ha (approximately 3000 gallons/acre or 84 kg N/ha) and urea fertilizer was applied at 84 kg N/ha on May 4, 2001. Potash (112 kg/ha) was also applied to the Bruce and Lilac fields at this time. On May 1, 2002 manure application was again 28m^3/ha, but urea fertilizer was applied at 112 kg N/ha (100 lbs/acre) on May 2, 2002. On April 28, 2003 manure was applied at the same rates as 2002 and 2001, but the urea fertilizer, also applied at the same rate as 2002, was applied as a side dress to the crop on June 9, 2003. In all three years starter fertilizer was applied according to the regular practice of the farm (213 kg/ha of 9-9-31-6).

Soil Sampling

Soil samples for determination of pre-plant N were collected before spring manure application at the 0-30cm and 30-60cm depths. Sampling occurred on April 23, 2001 (0-15cm samples for pH, Bray-P and potassium were also taken at this time); May 1, 2002; and March 1, 2003. These samples were composites of 10-15 samples taken the length of each plot, incorporating samples from in the row (site of banded manure injections) as well as between the rows. Cores were combined to give one sample at each depth per plot.

Soil samples were also collected for determinations of microbial biomass, potentially mineralizable N, total C and total N. These samples were taken at two depths (0-15cm and 15-30cm) and two times during the growing season each year: on July 3, 2001, July 18, 2002, and June 11, 2003 when the corn was in the V3 – V4 stage and again on August 23, 2001, August 27, 2002, and August 18, 2003 when the corn was in the early milk stage. Cores were taken at 19cm intervals across the third, fourth and fifth rows for a total of nine samples in different row positions; this was done twice in each plot. These samples were combined to give one 0-15cm sample and one 15-30cm sample per plot per sampling date. Soil samples were then taken back to the lab in a cooler, and stored at 4° C for analysis.

In the lab, soil samples were sieved to 4mm. Half of the sample was stored at field moisture content at 4° C. The other half was air dried and sieved to 2mm. Moisture content was determined by oven drying soils at 105°C overnight.

Laboratory Analysis

Microbial biomass C and an estimate of microbial biomass N were determined using the fumigation-incubation technique described by Jenkinson and Powlson (1976). Modifications from the procedure were the use of 25g of soil rather than 250g, fumigation of samples lasted 48 hours rather than 18-24 hours, and incubation of samples occurred in quart-sized Mason jars rather than confectionary jars (Rice et al., 1996). The samples were not inoculated before incubation and they were incubated for 10 days (Rice et al., 1996). Sodium hydroxide (NaOH; 1M) traps were included in the Mason jars; 5mls were used rather than 100mls. The NaOH traps were analyzed for inorganic carbon on a Tekmar Dohrmann Phoenix 8000 Carbon Analyzer (Tekmar Corporation, Mason, OH) to determine biomass C. The calculation used to determine biomass C was:

$$\text{Biomass C} = \frac{[\text{C in fumigated sample} - \text{C in control sample}]}{0.45}$$

Biomass N was determined by 2 M KCl extraction of 3.5g of the sample and analysis was conducted on a Lachat Quick Chem AE Ion Analyzer (Lachat Instruments, Milwaukee, WI).

The value for biomass N was calculated as the difference between the N content of the control and the fumigated samples. The constant of efficiency of extraction as described by Horwath and Paul (1994) was not calculated; therefore only the difference between fumigated and unfumigated samples is presented.

Potentially mineralizable nitrogen (PMN) was measured using the method outlined by Drinkwater et al. (1996). Modifications were made following the procedure in Bredja et al. (2000) as well as the following: 30g of soil were used instead of 40g and extractions were only performed on day zero (t_0) and 28 (t_{28}). From these 2 M KCl extractions, soil nitrate and ammonia were determined with a Lachat Quick Chem AE Ion Analyzer (Lachat Instruments, Milwaukee, WI) and used to calculate PMN. The calculation used to determine PMN was:

$$(t_{28}\ NH_4^+ + t_{28}\ NO_3^-) – (t_0\ NH_4^+ + t_0\ NO_3^-) = PMN$$

Total C and N were determined by ball milling air dried soil and analyzing a 0.25-0.4g sample on a Leco CN-2000 Elemental Analyzer (Leco Corp., St Joseph, MI). The pre-plant samples at the 0-30cm and 30-60cm intervals were dried at 60ºC and ground. Nitrogen content as well as pH, Bray-P, and K were determined by analysis at the University of Minnesota Soil Testing Lab.

Yield

Corn yield samples were taken in the field on September 10, 2001; September 4, 2002; and September 3, 2003. Ears were hand harvested from 12.16m in rows at the center of the plot which were representative of the treatment area. Husks were removed and ears were weighed in the field and then dried at 77ºC for one week to determine grain yield and field moisture content. Results were reported as kg/ha of grain yield at 15.5% field moisture. The stover was measured from stalks cut from a 6.08m length of row. The stalks were chipped and weighed on the farm. A subsample of the chipped stover was taken back to the lab, dried at 77ºC for one week and weighed to determine field moisture. These results were reported as total dry matter per hectare.

Manure Sampling and Testing

Raw and lagoon stored manure was sampled in the Spring of 2001 and 2002. Samples were also taken regularly from the Fall of 2002 to Summer of 2003. The raw manure was sampled in October 2002, and in March, twice in April, May, June, July, and August, 2003 from a holding tank that is located prior to the digester in the manure stream. The digested manure was sampled at these same times directly after digestion and before the manure was piped into the lagoon. The lagoon samples could only be obtained in October 2002, and both times in April, June, July and August 2003 when manure was being applied to the fields and therefore the lagoon contents had been mixed. Manure was sampled using a catch bucket on the end of a pole. The tank holding raw manure is regularly stirred before the manure is pushed into the digester, leaving a fairly homogenous mixture. After digestion the manure is free-flowing and also fairly homogeneous. The lagoon samples were taken when they would be as homogeneous as possible, as the manure was pumped from the lagoon into the spreader. All the manure samples were taken back to the lab and frozen until they could be analyzed.

For each date collected, an aliquot of the frozen sample was sent to the University of Wisconsin Soil and Forage Analysis Lab in Marshfield, Wisconsin to be analyzed for total N, total P, total K, and sulfur (S). The samples from 4/28/2003 were also analyzed for total C and the remainder was used for the manure incubations.

Manure Incubations

Three rates of manure application were selected to test for plant available N content of raw, digested and lagoon stored manure. The first rate was equal to the rate applied to the plots, $28m^3$/ha (3000 gallons/acre). The second rate was the rate the farmer usually applies (56 m^3/ha or 6000 gallons/acre) and the third rate was a very high rate of 140 m^3/ha (15000 gallons/acre) used as a comparison. To achieve these rates 10mls of manure was added to 1kg soil for the $28m^3$/ha rate, 20mls for the $56m^3$/ha rate and 50mls for the $140m^3$/ha rate. Soil collected from the Bruce field was sieved to 2mm and air dried; manure was added and mixed thoroughly.

This incubation procedure was modeled after the PMN procedure described previously, with the following modifications. Samples were extracted at the following times: 0, 14, 28, 42, and 56 days after experimental set up. The duration of the incubation was extended in order to capture the entire curve of activity as in Pilar Bernal and Kirchmann (1992) and Hadas et al. (1983). Manure was added to the soil and three repetitions of each type of manure and each time point were incubated in pint-sized Mason jars at 25ºC. Samples were extracted with 2 M KCl and analyzed on a Lachat Quick Chem AE Ion Analyzer (Lachat Instruments, Milwaukee, WI) to determine total available N.

Soil blanks as well as urea controls were incubated along with the manure incubations. The amount of urea added to 1kg of soil was determined by measuring the NH_4 extracted from 25mls of manure with 1.0 L of double deionized water. The samples were shaken for 30 minutes, centrifuged and analyzed on a Wescan Analyzer (Wescan Instruments Inc., Santa Clara, CA). An amount of urea equivalent to the amount of NH_4 in the manure was added to soil and incubated for the same time periods and at the same temperature as the manure. These samples were also extracted with 2 M KCl and analyzed on a Lachat Quick Chem AE Ion Analyzer (Lachat Instruments, Milwaukee, WI). The total N values for the soil blanks were subtracted from the urea blanks to determine the effect of adding the urea to the soil. This value was then subtracted from the manure incubation value to determine the amount of N that becomes available to plants from the organic N fraction.

As with the biomass procedure, 5ml NaOH traps were placed in the Mason jars to monitor C respired per day during the incubation. These traps were placed, along with the samples, in the pint sized Mason jars and were not removed or changed until the samples were removed for extraction. The traps were analyzed for inorganic carbon on a Tekmar Dohrmann Phoenix 8000 Carbon Analyzer (Tekmar Corporation, Mason, OH). The calculation to determine respired C per day was:

$$\frac{\text{C collected in trap}}{\text{days incubated}} = \text{respired C per day}$$

As described in the previous paragraph, the C values from the soil blanks were subtracted from the urea controls, and that value was subtracted from the manure values. Thus respired C reported is solely the net effect of the given amendment.

Statistical analyses in this study were conducted using the GLM procedure of SAS using SAS V8 software (SAS Institute, 1999). Each soil quality and crop yield parameter was analyzed by grouping the three replicates of inorganic fertilizer or manure application within each field. Coefficients of variation (CVs) and LSD values for balanced data were reported in the output from the GLM procedure. P-values of 0.1 were chosen to increase the probability of detecting treatment differences. LSD values for unbalanced data were calculated by hand, using error and t-values generated by the SAS program. Unbalanced data resulted from missing values; in 2001 these occurred in the digested manure replications in both the Appel and Bruce fields. In 2003 missing data was from the raw manure replication in the Bruce field and from raw and digested manure and inorganic fertilizer replications in the Lilac field depending on the sampling time and variable tested. Coefficients of variation were high for all measured properties. This variability is due to two factors: (1) the inherent soil variability at this glacial outwash site; and (2) the fact that the variables measured were at very low levels on this naturally infertile, sandy soil, so that small differences between measured values resulted in large CVs.

Results and Discussion

Yield and Pre-Plant Nitrogen

A major concern for farmers when the fertilizer source is changed is the resulting crop yield. There were few differences in crop yield among the different amendments (Table 2).

Table 2. Effect of Fertilizer Type and Application Frequency on Grain and Stover Yield, Haubenschild Farm, Princeton, MN 2001-2003

Date of Sampling			Grain Yield			Stover Yield		
			2001	2002	2003	2001	2002	2003
Field	Application Frequency	Nutrient Source	----------kg/ha @15.5% Moisture----------			---------------------TDM/ha----------------		
Appel	Annual	Digested Manure	6951.40	6698.68	5647.66	2.05	2.38	1.39
		Raw Manure	6701.19	5733.57	2932.95	2.24	2.12	0.81
		Inorganic Fertilizer	6549.43	6920.05	6496.76	2.04	2.42	1.54
		LSD[1]	NS[2]	NS	1839.91	NS	NS	0.42
Appel	Biennial	Digested Manure	--	--	1762.78	--	--	0.54
		Raw Manure	--	--	3864.82	--	--	0.99
		Inorganic Fertilizer	--	--	1836.77	--	--	0.43
		LSD	--	--	NS	--	--	NS
Bruce	Annual	Digested Manure	6973.35	6219.58	3846.00	2.17	1.88	1.02
		Raw Manure	7071.81	5149.74	4477.49	2.21	1.55	1.25
		Inorganic Fertilizer	6926.32	6382.62	3326.14	2.26	1.78	0.99
		LSD	NS	NS	NS	NS	NS	NS
Bruce	Biennial	Digested Manure	--	3519.28	3616.48	--	1.02	1.05
		Raw Manure	--	2393.01	3826.56	--	0.79	1.12
		Inorganic Fertilizer	--	3517.40	2522.82	--	1.04	0.81
		LSD	--	NS	NS	--	NS	NS
Lilac	Annual	Digested Manure	5393.69	4802.96	4746.52	2.17	1.94	1.20
		Raw Manure	5218.10	5159.15	4853.13	2.15	1.96	1.44
		Inorganic Fertilizer	4502.58	5000.49	3795.84	2.02	1.93	1.06
		LSD	NS	NS	NS	NS	NS	NS
Lilac	Biennial	Digested Manure	--	3970.80	4384.06	--	1.56	1.25
		Raw Manure	--	3568.20	3230.82	--	1.43	0.85
		Inorganic Fertilizer	--	4932.14	4323.85	--	1.75	1.21
		LSD	--	NS	NS	--	NS	NS

[1]LSD ($p<0.1$) refers to the three preceding nutrient sources within the indicated application frequency and field

[2] NS designates instances where results for the nutrient sources were not significantly different

The only differences observed in grain or stover yield were for the annual application on the Appel field in 2003 where raw manure yielded less than the other two amendments. For all three fields, the lack of a pattern in the rank order of treatments, as well as the lack of treatment differences both suggest that there were no yield differences among the amendments. However, variability was quite high especially in 2002 and 2003. Grain yield CVs for 2001 were 11-17%, in 2002 17-37%, and in 2003 18-53%. In 2001, stover yield CVs were 11-16%, in 2002 23-46%, and in 2003 18-53%. Our yield results are similar to those of Susse and Wurzinger (1986) who applied stored pig and cattle manure to a grassland, as well as Dahlberg, et al. (1988) using digested dairy manure on wheat in a greenhouse. Neither study showed differences in crop yield for digested versus raw manure.

Pre-plant N measurements were also highly variable (CVs 2001: 19-38%, 2002: 14-28%, 2003: 10-22%). The large CVs resulted from high inherent soil variability and low nitrogen values at this field site. Again, there was no pattern of differences among the nutrient sources as measured by pre-plant N (Table 3). The only difference observed in 2001 was in the Lilac field (30-60cm) where digested manure had higher pre-plant N than inorganic fertilizer. In 2002, differences occurred at the 30-60cm depth in the biennial application of both the Bruce field (raw manure was greater than the other amendments) and the Lilac field (inorganic fertilizer was less than the other amendments). Differences in 2003 were in the biennial applications (both depths) on the Appel field and annual (30-60cm) and biennial (0-30cm) applications on the Bruce field. Of the six cases where differences occurred, raw manure had the highest pre-plant N values twice and the lowest values once, inorganic fertilizer was highest once and lowest once, and digested manure was lowest once. This lack of consistent differences in pre-plant N among the treatments suggests that amounts of N supplied to the crop were generally similar for each of the nutrient sources.

Table 3. Effect of Fertilizer Type and Application Frequency on Pre-plant Nitrogen, Haubenschild Farm, Princeton, MN 2001-2003

Date of Sampling			Pre-plant Nitrogen 2001		2002		2003	
Depth in cm			0-30	30-60	0-30	30-60	0-30	30-60
Field	Application Frequency	Nutrient Source	---mg/kg---					
Appel	Annual	Digested Manure	5.37	3.38	4.07	2.73	4.30	3.90
		Raw Manure	6.40	3.33	4.42	2.82	3.47	3.23
		Inorganic Fertilizer	5.32	3.40	4.33	2.73	3.87	3.70
		LSD[1]	NS[2]	NS	NS	NS	NS	NS
Appel	Biennial	Digested Manure	--	--	--	--	3.63	3.23
		Raw Manure	--	--	--	--	4.13	3.47
		Inorganic Fertilizer	--	--	--	--	3.40	2.87
		LSD	--	--	--	--	0.41	0.50
Bruce	Annual	Digested Manure	3.38	3.37	2.63	2.40	3.73	2.73
		Raw Manure	4.07	2.73	2.70	2.00	4.56	3.25
		Inorganic Fertilizer	2.78	2.70	3.27	1.90	4.13	3.53
		LSD	NS	NS	NS	NS	NS	0.73
Bruce	Biennial	Digested Manure	--	--	2.23	1.63	3.70	2.77
		Raw Manure	--	--	2.53	2.70	2.87	2.67
		Inorganic Fertilizer	--	--	2.40	1.83	4.25	3.17
		LSD	--	--	NS	0.63	0.64	NS
Lilac	Annual	Digested Manure	7.58	5.17	4.50	4.13	4.68	3.50
		Raw Manure	6.30	5.18	3.70	3.43	4.77	4.07
		Inorganic Fertilizer	6.07	3.65	3.70	4.10	3.53	3.43
		LSD	NS	1.32	NS	NS	NS	NS
Lilac	Biennial	Digested Manure	--	--	4.57	5.33	3.67	3.47
		Raw Manure	--	--	4.47	5.50	3.93	3.43
		Inorganic Fertilizer	--	--	3.73	3.70	4.30	3.53
		LSD	--	--	NS	1.19	NS	NS

[1] LSD (p<0.1) refers to the three preceding nutrient sources within the indicated application frequency and field.

[2] NS designates instances where results for the nutrient sources were not significantly different

Total Carbon and Nitrogen

Total C results (Table 4) were highly variable (CVs 2001: 12-48%, 2002: 11-47%, 2003: 4-51%). In 2001, the only areas that exhibited treatment differences were the Appel (0-15cm) and Bruce (15-30cm) fields in July, with inorganic fertilizer having higher total C than digested manure in both cases. In July of 2002, the Bruce field was the only field showing differences. These differences occurred in both application frequencies and at both depths. Of these four cases, digested manure was lower than other amendments twice in the annual application and raw manure was lower than inorganic fertilizer twice in the biennial treatment. In the August sampling, only the annual treatment in the Bruce field showed differences, with digested manure having lower total C than the other amendments at both depths.

In August, 2003, the Appel field (annual treatment 0-15cm, biennial treatment both depths) exhibited three differences, while the Bruce field only showed one (biennial treatment, 15-30cm). Digested manure had greater total C than raw manure once and less total C than raw manure once. Raw manure was lower than the other nutrient sources once, and inorganic fertilizer was lower than the other sources once. In the 12 out of 56 possible cases where differences were detected, inorganic fertilizer has higher total C than the other amendments in 9 cases, raw manure in 6, and digested manure in 3. Digested manure had lower C in 7 cases, raw manure in 4, and inorganic fertilizer only once.

Total N also did not differ much among treatments over the three years of sampling (Table 5), but again showed high variability (CVs 2001: 12-113%, 2002: 13-72%, 2003: 10-118%). Differences observed in total N generally paralleled the differences in total C. In 2001, differences were in the July sampling at 0-15cm in the Appel field, with inorganic fertilizer having higher values than digested manure, and the Bruce field, where inorganic fertilizer was higher than both the other amendments. In 2002, the Bruce field, annual treatment, was the only area that exhibited differences. The digested manure had less total N than the other amendments in both the July sampling (0-15cm) and the August sampling (both depths). The Appel field, biennial treatment, was the only field with any differences in 2003. The June sampling (15-30cm) and the August sampling (0-15cm) both show inorganic fertilizer differing from the other two amendments, in one case greater and the other less. In the 7 cases out of 56 possible where differences occurred, inorganic fertilizer was greater in 6, raw manure was greater in 4, and digested manure was greater in only one. Inorganic fertilizer had lower total N in only one case, raw manure in 2, and digested manure in 6 cases. Trends in the results for total C and N suggest that there may be less total C and N supplied by digested manure than by raw manure or inorganic fertilizer. However, differences occurred only 13% (total N) to 21% (total C) of the time. Parham et al. (2002) also found no differences in total C and N in plots fertilized with manure or inorganic fertilizer, though additions of either input increased total C and N over unfertilized plots.

Table 4. Effect of Fertilizer Type and Application Frequency on Total Soil Carbon, Haubenschild Farms, Princeton, MN 2001-2003

			Total Soil Carbon											
Date of Sampling			July 2001		August 2001		July 2002		August 2002		June 2003		August 2003	
Depth in cm			0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Field	Application Frequency	Nutrient source	g/kg											
Appel	Annual	Digested Manure	9.53	7.02	6.22	7.67	9.30	6.02	8.05	6.07	8.83	5.43	8.83	6.94
		Raw Manure	10.45	6.79	7.41	6.07	8.44	6.07	8.77	5.64	8.33	5.06	7.81	6.16
		Inorganic Fertilizer	10.99	7.49	7.32	7.02	8.07	5.76	7.92	5.36	8.17	5.24	8.60	7.11
		LSD[1]	1.30	NS[2]	NS	NS	NS	NS	NS	NS	NS	NS	0.64	NS
Appel	Biennial	Digested Manure	--	--	--	--	--	--	--	--	7.84	4.12	6.72	6.03
		Raw Manure	--	--	--	--	--	--	--	--	8.26	5.25	8.74	6.13
		Inorganic Fertilizer	--	--	--	--	--	--	--	--	8.01	3.99	7.21	4.56
		LSD	--	--	--	--	--	--	--	--	NS	NS	1.71	1.17
Bruce	Annual	Digested Manure	5.55	4.58	8.61	8.19	5.37	4.05	5.38	4.31	5.18	3.79	5.39	5.56
		Raw Manure	6.28	5.27	6.72	6.94	7.37	5.73	6.92	6.11	8.54	5.62	7.41	6.71
		Inorganic Fertilizer	6.92	6.22	9.46	6.81	7.34	6.51	7.17	6.25	7.10	5.88	6.84	6.32
		LSD	NS	1.44	NS	NS	1.94	1.83	1.26	1.21	NS	NS	NS	NS
Bruce	Biennial	Digested Manure	--	--	--	--	5.76	4.58	6.37	4.81	6.29	4.61	6.06	5.73
		Raw Manure	--	--	--	--	4.54	3.76	5.13	4.01	5.72	3.65	4.89	4.20
		Inorganic Fertilizer	--	--	--	--	6.55	5.64	6.42	5.69	5.90	4.83	5.97	4.96
		LSD	--	--	--	--	1.83	1.62	NS	NS	NS	NS	NS	1.23
		Digested Manure	8.09	8.05	8.24	6.52	8.74	8.01	8.77	7.38	8.67	7.43	8.33	9.08
Lilac	Annual	Raw Manure	8.07	7.74	10.59	8.00	8.95	8.22	8.41	8.09	8.97	6.72	8.76	8.35
		Inorganic Fertilizer	6.22	8.69	8.25	7.89	5.87	5.90	5.99	5.98	6.05	5.36	5.89	6.94
		LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
		Digested Manure	--	--	--	--	6.73	6.39	6.65	6.64	6.06	5.89	5.89	6.78
Lilac	Biennial	Raw Manure	--	--	--	--	5.84	5.38	5.71	6.05	5.11	4.50	5.29	5.84
		Inorganic Fertilizer	--	--	--	--	8.44	7.67	8.39	6.93	9.69	7.01	8.07	7.71
		LSD	--	--	--	--	NS	NS	NS	NS	NS	NS	NS	NS

[1] LSD (p<0.1) refers to the three preceding nutrient sources within the indicated application frequency and field.

Table 5. Effect of Fertilizer Type and Application Frequency on Total Soil Nitrogen, Haubenschild Farms, Princeton, MN 2001-2003

			Total Soil Nitrogen											
Date of Sampling			July 2001		August 2001		July 2002		August 2002		June 2003		August 2003	
Depth in cm			0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Field	Application Frequency	Nutrient Source	---mg/kg---											
Appel	Annual	Digested Manure	542	294	287	478	637	379	524	360	427	275	697	361
		Raw Manure	613	349	302	203	584	350	543	314	377	227	535	286
		Inorganic Fertilizer	656	311	244	304	561	451	501	307	573	423	662	353
		LSD[1]	77	NS[2]	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Appel	Biennial	Digested Manure	–	–	--	--	--	–	–	--	453	157	538	236
		Raw Manure	–	–	--	--	--	–	–	--	352	150	524	273
		Inorganic Fertilizer	–	–	--	--	--	–	–	--	595	459	417	140
		LSD	–	–	--	--	--	–	–	--	NS	250	89	NS
Bruce	Annual	Digested Manure	193	225	773	620	209	183	213	200	110	219	166	211
		Raw Manure	275	225	251	284	364	224	380	303	212	153	383	436
		Inorganic Fertilizer	452	266	559	313	381	298	419	320	242	233	385	456
		LSD	127	NS	NS	NS	132	NS	136	100	NS	NS	NS	NS
Bruce	Biennial	Digested Manure	–	–	--	--	254	246	371	306	186	153	349	203
		Raw Manure	–	–	--	--	285	296	290	188	88	302	149	122
		Inorganic Fertilizer	–	–	--	--	290	247	372	300	249	145	306	188
		LSD	–	–	--	--	NS	NS	NS	NS	NS	NS	NS	NS
Lilac	Annual	Digested Manure	600	493	436	251	605	511	629	504	1200	557	566	647
		Raw Manure	528	464	869	453	710	590	640	572	1100	459	1060	642
		Inorganic Fertilizer	335	624	431	359	326	326	422	354	155	152	358	467
		LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Lilac	Biennial	Digested Manure	–	–	--	--	408	348	540	473	277	181	326	476
		Raw Manure	–	–	--	--	326	250	361	416	369	264	231	370
		Inorganic Fertilizer	–	–	--	--	595	498	607	501	548	444	736	523
		LSD	–	–	--	--	NS	NS	NS	NS	NS	NS	NS	NS

[1]LSD refers to the three preceding nutrient sources within the indicated application frequency and field.

[2]NS designates instances where results for the nutrients sources were not significantly different

Labile C and N Pools

Measures of microbial biomass and PMN also exhibited high amounts of variability, but did not show differences among the nutrient sources. At the Haubenschild farm, the range of CVs for microbial biomass C (MBC) was 11-57% in 2002 and 10-56% in 2003 and for microbial biomass N (MBN) was 15-45% in 2002 and 13-48% in 2003. In these years only a few differences in microbial biomass were detected (Figure 5&6, Appendix A for data).

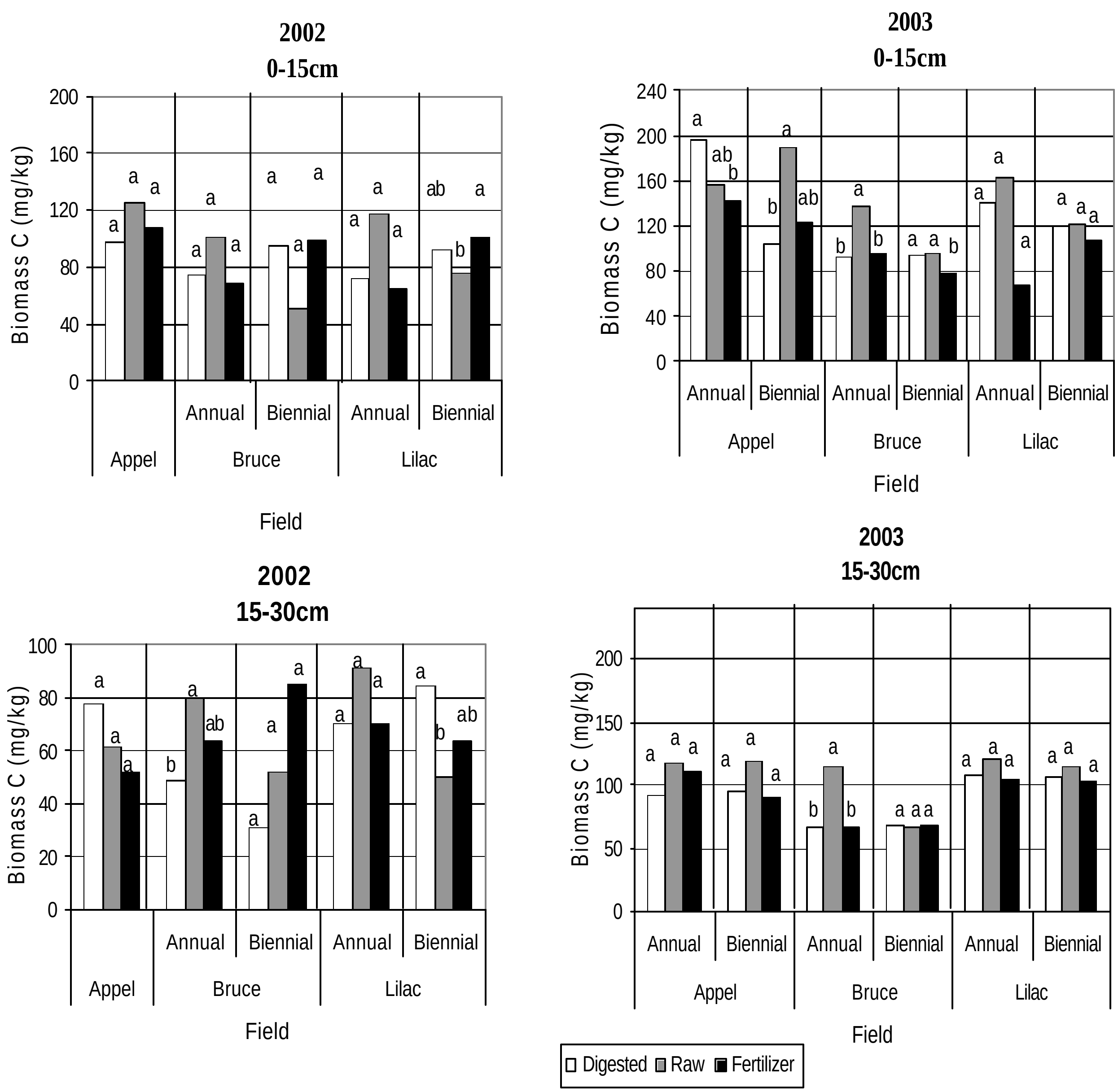


Figure 5. Nutrient Source Effect on Microbial Biomass Carbon, Haubenschild Farms, Princeton, MN 2002-2003

In 2002, MBC exhibited differences in the Bruce and Lilac fields with MBC for digested manure greater than raw manure once, raw manure greater than digested manure once and inorganic fertilizer greater than raw manure once. In 2003, differences occurred in the Appel and Bruce fields where digested manure had higher MBC than inorganic fertilizer once, raw manure was greater than digested manure once, raw manure was greater than the other nutrient sources twice, and inorganic fertilizer was less than the other amendments once. In 8 out of 22 possible cases where differences occurred, raw manure resulted in higher MBC in 5 cases, digested manure in 3, and inorganic fertilizer only once. Raw manure had less MBC only twice, and digested manure and fertilizer were lower in 4 cases each.

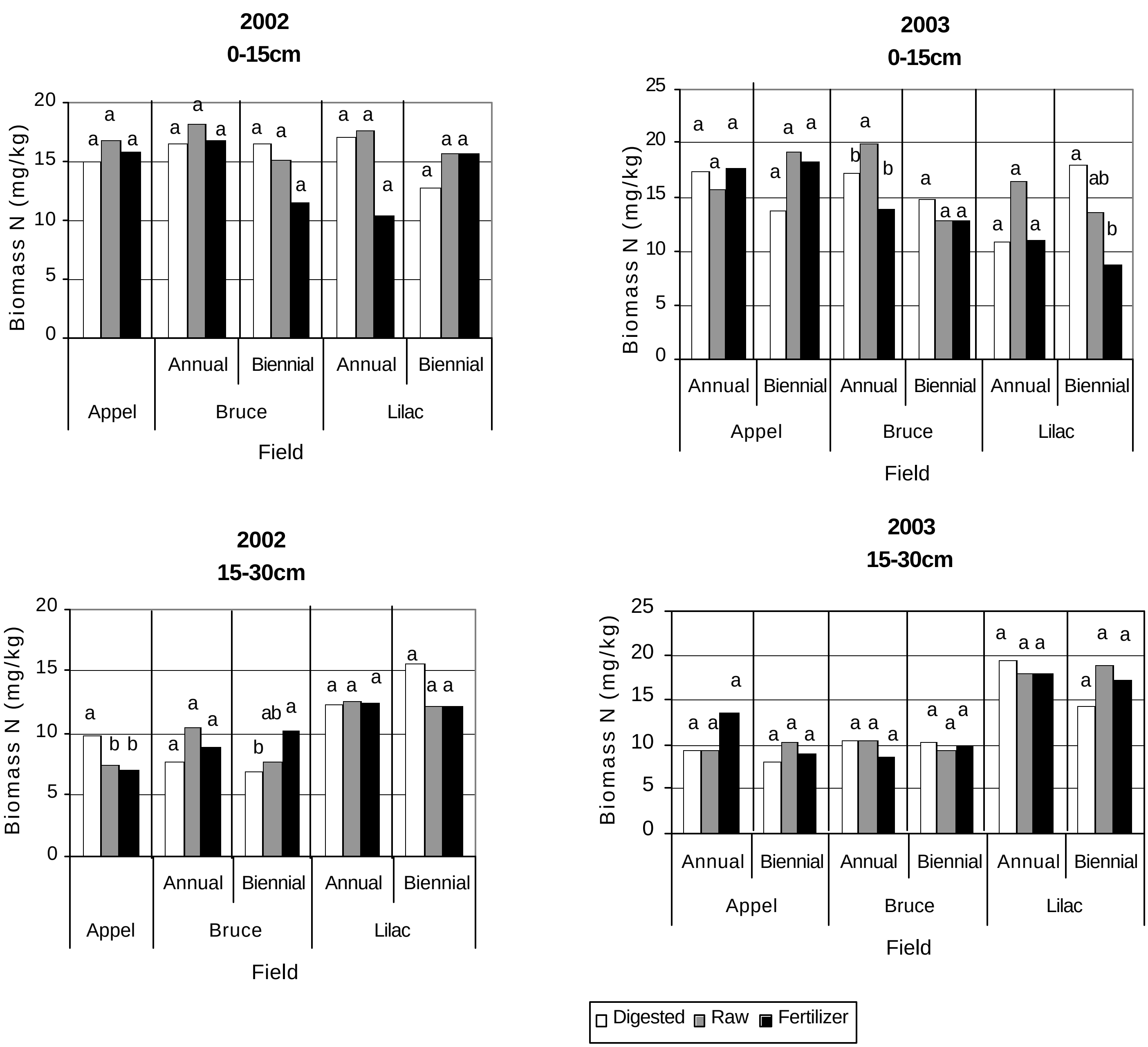


Figure 6. Nutrient Source Effect on Microbial Biomass Nitrogen, Haubenschild Farms, Princeton, MN 2002-2003

In 2002, MBN revealed differences in the Appel and Bruce fields (both at 15-30 cm) with digested manure MBN greater than the other nutrient sources once and digested manure less than inorganic fertilizer once. In 2003, the differences occurred in the Bruce field (0-15 cm), with raw manure MBN greater than the other amendments, and in the Lilac field (0-15 cm), with digested manure greater than inorganic fertilizer. MBN differed in only 4 out of 22 possible cases, with digested manure amounts greatest twice, raw manure once and inorganic fertilizer once. Raw manure MBN was less than the others only once, while digested manure was lower twice and inorganic fertilizer 3 times. Where differences occurred, it appears that manure sources were better than inorganic fertilizer for increasing MBC and MBN.

The Lilac and Appel fields both tended to have higher amounts of microbial biomass C and N than the Bruce field. This difference may be due to the lack of historical manure application in the Bruce field, and therefore limited substrate for microbes. Others have shown that manure additions to a site will increase the microbial biomass (Friedel et al., 1996; Parham et al., 2002; Peacock et al., 2001). The Lilac field and Appel field had relatively equal amounts of microbial biomass C and N which could be attributed to the long history of manure application prior to this study.

PMN is a test to determine how much N could become available to plants over the growing season. Robbins et al. (1997) determined that amounts of PMN are greater in unfermented manure than in inorganic fertilizer. Friedel et al. (1996) showed that anaerobically fermented manure, which is similar to digested manure, had higher amounts of PMN than unfermented manure. Results from the plots at the Haubenschild's farm exhibit a high degree of variability (CVs 2001: 13-62%, 2002: 9-30%, 2003: 6-142%), but show few differences in PMN for the different amendments (Figure 7&8, Appendix B for data).

In July, 2001, PMN was greater in the Bruce field (0-15 cm) for the fertilizer treatment than the digested manure treatment. In August, 2001, PMN was greater for raw manure than for digested manure in the Appel field and was greater for raw manure than either of the other two sources in the Bruce field (15-30 cm). In 2002, the Bruce field showed three differences: digested manure PMN less than the other two amendments, inorganic fertilizer greater than the other amendments, and inorganic fertilizer greater than digested manure. Other differences in 2002 included the Appel field (15-30 cm), with digested manure greater than inorganic fertilizer, and the Lilac field (15-30 cm), with raw manure greater than digested manure. In 2003, the Appel and Bruce fields were the areas where differences occurred. Raw manure was greater than inorganic fertilizer twice and inorganic fertilizer was less than both the other amendments once. Based on the cases where differences were evident, raw manure application resulted in greater amounts of PMN than digested manure, but differences occurred in only 11 out of 56 possible cases.

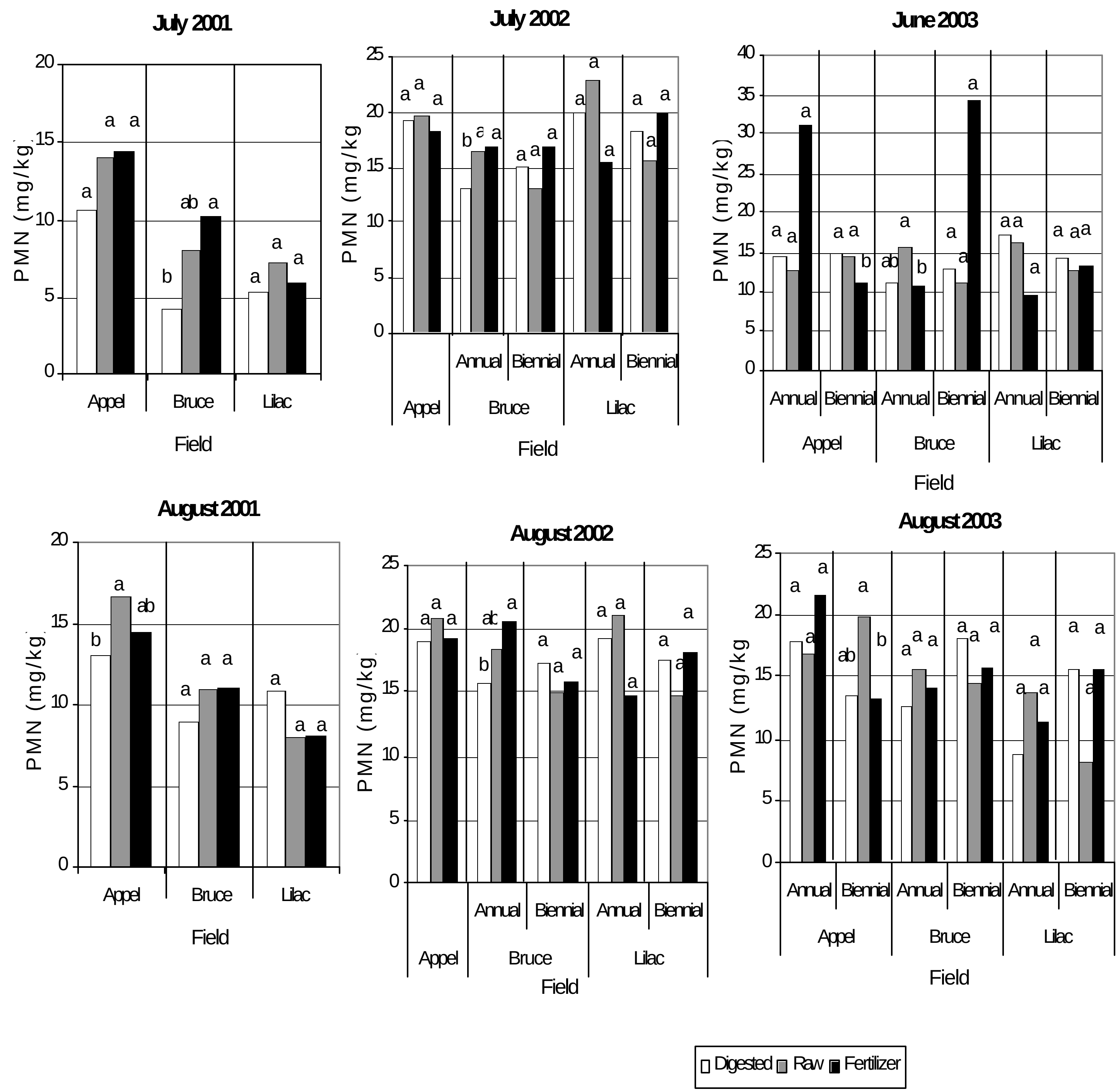


Figure 7. Nutrient Source Effect on PMN at 0-15cm depth during a 28 day Incubation, Haubenschild Farms, Princeton, MN 2001-2003

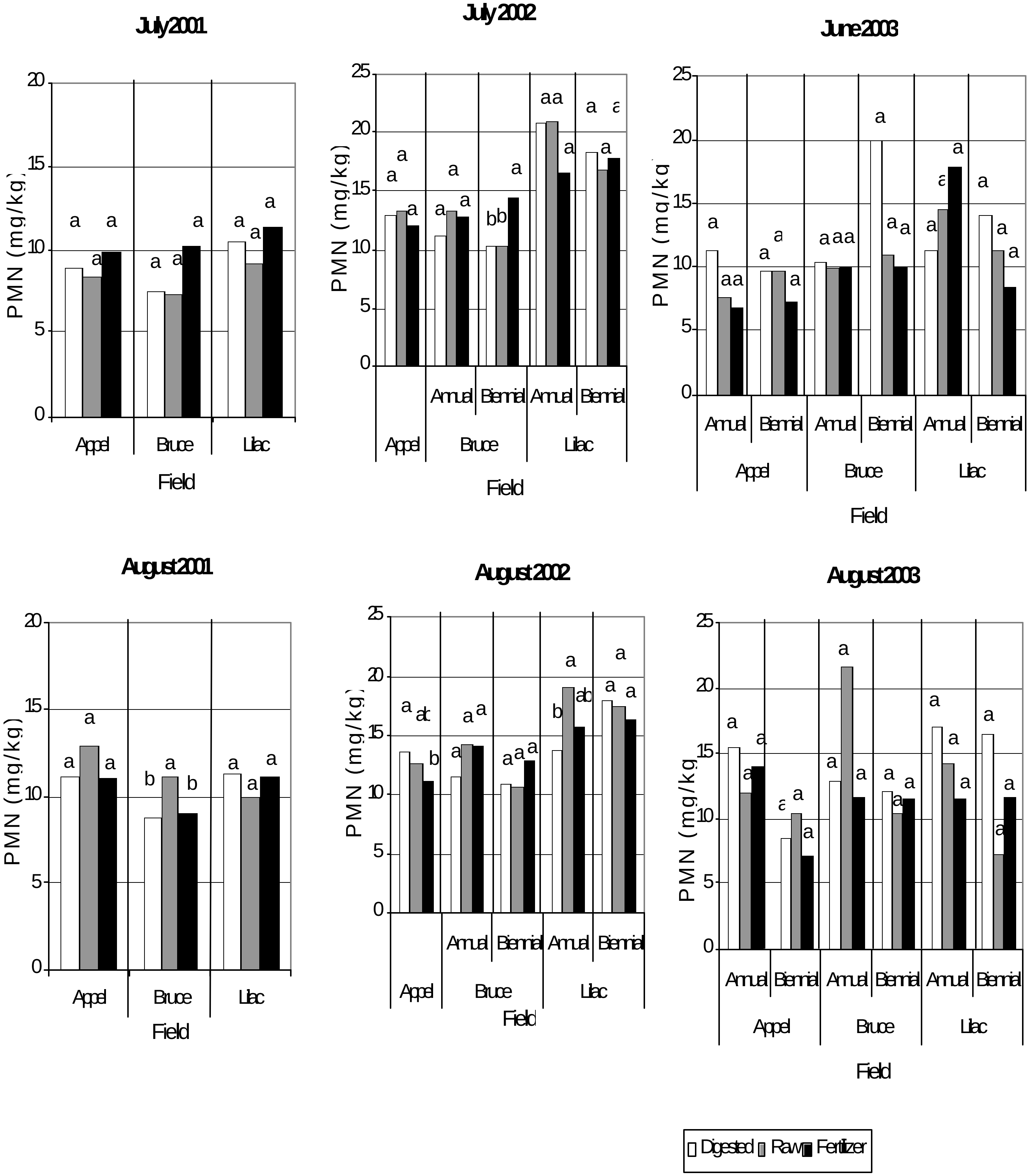


Figure 8. Nutrient Source Effect on PMN at 15-30 cm depth during a 28 day Incubation, Haubenschild Farms, Princeton, MN 2001-2003

Nutrient Pool Changes over Time

Other researchers have shown that manure additions continue to build soil C and N over a long period of time. This accumulation occurs even if small amounts of manure are applied (Peacock et al., 2001; Rochette and Gregorich, 1998). During the three years of this study, total C stayed fairly constant, but three years may not be long enough to see increases and smaller amounts of manure were applied than the usual farm practice. Nitrogen did not increase from 2001-2003 in the Lilac or Appel fields, but since these fields had a history of manure application, levels were already relatively higher in the 2001 samplings. In the Lilac field, where alfalfa preceded the corn crop planted in 2001, pre-plant N decreased over the three years of the study. By the third year there was a slight increase in the total N of the Bruce field, a field with no history of manure application.

Other nutrient levels in the three fields stayed constant or slightly decreased over the three years (Table 6), possibly due to the purposeful application of amendments at levels below those recommended for optimum corn yield. Potassium increased in the Bruce and Lilac fields after application of 112 kg/ha of potash in 2001 and starter fertilizer containing K each year. Extra K was applied to these fields to increase previously low levels determined by soil tests. After an initial increase these higher levels of K were maintained throughout the study.

Table 6. Soil pH, Bray-P and Potassium, Haubenschild Farms, Princeton, MN 2003 (0-30cm)

Table 5 Soil pH, Bray-P and Potassium in 2003 (0-30cm)

Field	Application Frequency	N Source	pH	Bray-P (ppm)	Potassium (ppm)
Appel	Annual	Digested Manure	6.83	65.00	139.67
		Raw Manure	7.00	55.33	136.33
		Inorganic Fertilizer	6.86	63.16	148.33
		LSD[1]	NS[2]	NS	10.31
Appel	Biennial	Digested Manure	6.96	54.33	142.00
		Raw Manure	6.93	66.00	138.66
		Inorganic Fertilizer	7.00	57.00	137.00
		LSD	NS	NS	NS
Bruce	Annual	Digested Manure	6.33	36.33	96.66
		Raw Manure	6.36	28.66	118.00
		Inorganic Fertilizer	6.20	28.83	102.33
		LSD	NS	NS	11.83
Bruce	Biennial	Digested Manure	6.20	30.33	99.66
		Raw Manure	6.17	37.33	87.33
		Inorganic Fertilizer	6.00	28.33	93.66
		LSD	NS	7.85	NS
Lilac	Annual	Digested Manure	6.20	74.33	123.33
		Raw Manure	6.10	85.66	123.33
		Inorganic Fertilizer	5.96	73.00	95.67
		LSD	0.18	NS	NS
Lilac	Biennial	Digested Manure	6.03	70.67	108.67
		Raw Manure	6.27	75.16	113.50
		Inorganic Fertilizer	6.07	80.33	117.67
		LSD	NS	NS	NS

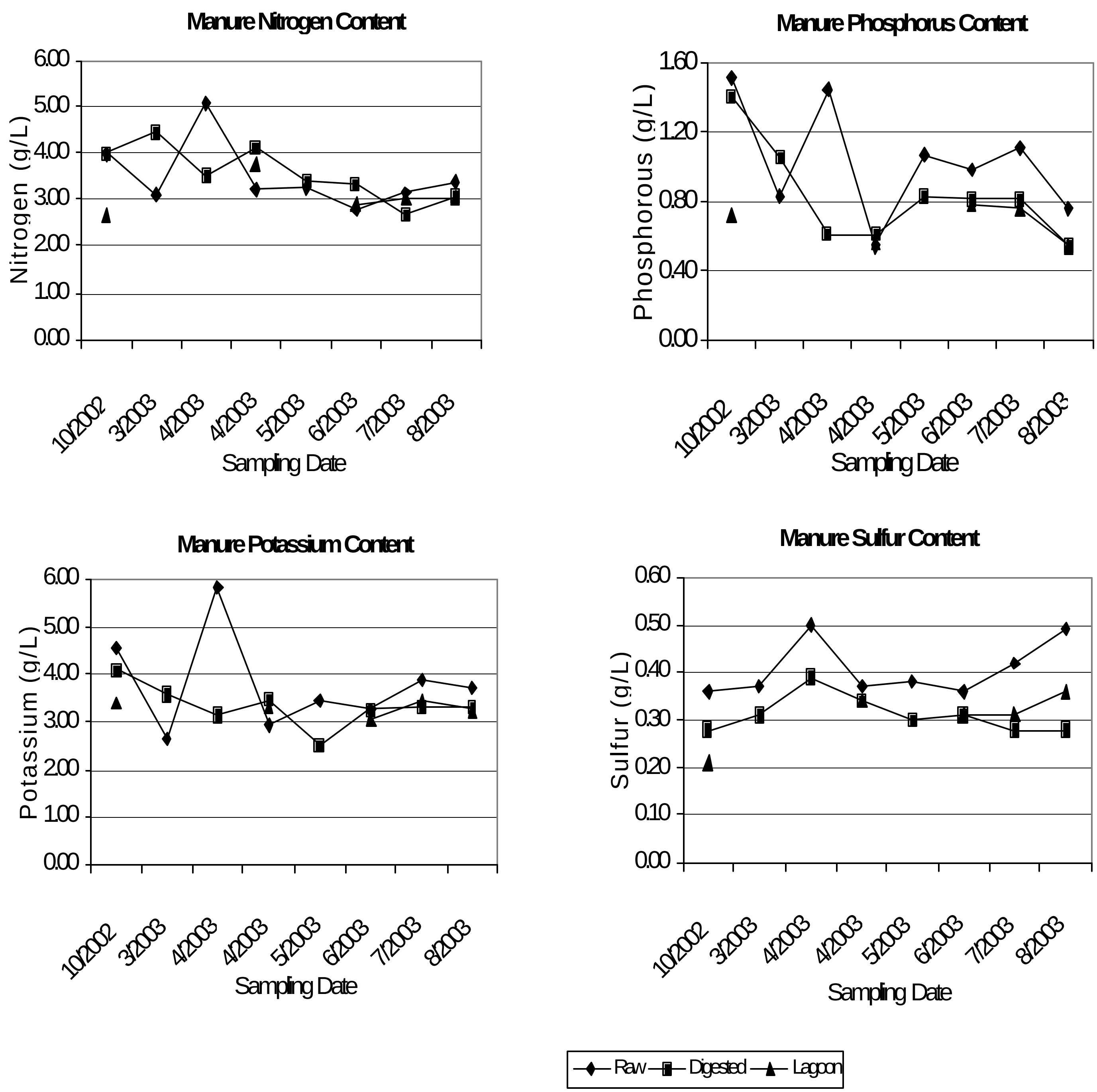
[1]LSD ($p<0.1$) refers to the three preceding N sources within the indicated application frequency and field

[2]NS designates instances where results for the nutrient sources were not significantly different

Manure Nutrient Concentrations

Manure was collected from three different locations on the Haubenschild's farm (raw manure from a holding tank before the digester, digested manure as the manure came out of the digester, and lagoon manure as the manure was pumped into the spreader) and was analyzed for N, P, K, and S. Nitrogen, K and S were relatively stable and N and K were at similar concentrations during this one year period, except for the first April sampling date, when the raw manure had increases of 22-54% over average values (Figure 9, Appendix C for data).

Figure 9. Raw, Digested and Lagoon Manure Nutrient Concentrations over Time, Haubenschild Farms, Princeton, MN



Raw and digested manure exhibited high P values in the October, 2002 sampling, decreasing to lagoon levels throughout the rest of the sampling dates. Sulfur also appeared to increase in July and August 2003; otherwise the three different manure sources differ little over the sampling period. When averaged over time, S was the only nutrient showing a difference between raw and digested manure (Table 7). Manure collected in the Spring of 2001 and 2002 had concentrations of N, P, and K that were similar to the Spring samples in 2003.

Table 7. Average Raw, Digested and Lagoon Manure Nutrients voer Time,
Haubenschild Farms, Princeton, MN

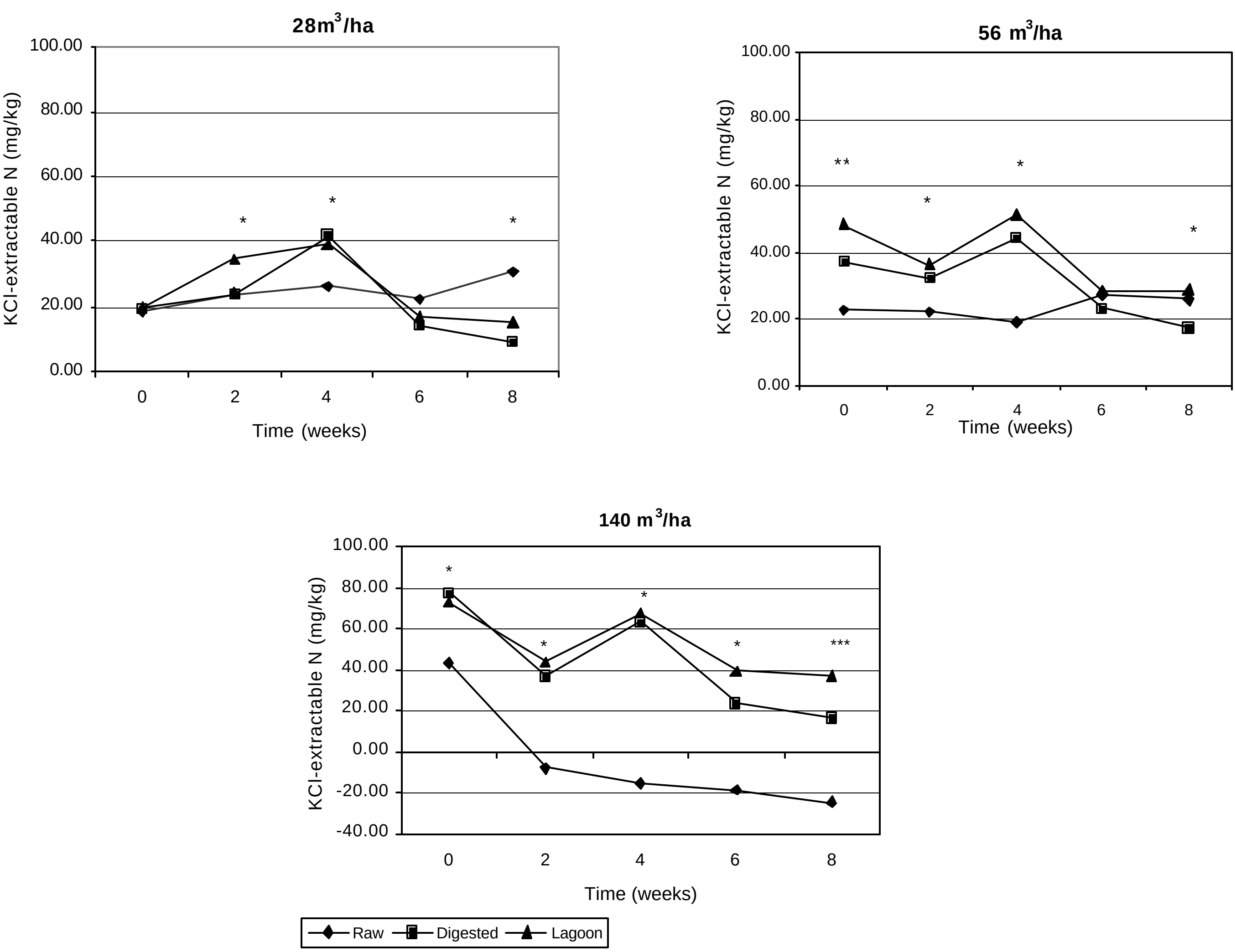
Manure Type	**Nitrogen**	**Phosphorus**	**Potassium**	**Sulfur**
	---------------------	**----------------g/L--**	**----------------------**	
Raw	3.50a	1.03a	3.78a	0.41a
Digested	2.58a	0.83a	3.34a	0.31b
Lagoon*	3.08	0.67	3.29	0.31

*Because only a few lagoon samples could be collected, they were not included in the ANOVA and LSD calculation

These results agree with Van Horn et al. (1994) who determined that N, P, and K levels are consistent between raw and digested manure. Nitrogen is the nutrient most easily lost from storage and DeLuca and DeLuca (1997) estimate that losses are between 30% and 60% of the N from feedlot manure in open lot storage; however, Thomsen (2000) found that N lost from anaerobically stored sheep manure is only about 18%. These studies agree that only small differences are detected in the total nutrient concentrations for digested versus raw manure. At the Haubenschild farm manure handling and storage practices seem to be conserving nutrients quite well, even in the lagoon.

Manure Incubations

Unlike the field results, manure incubations in this study did show differences in net rates of N mineralization among different manure types. Differences in KCl-extractable N were most pronounced at the highest rate of application (Figure 10).



gure 10. Net Extractable Nitrogen Attributable to Manure Source by Application Rate during 8 week Incubation

* Indicates a time point where one manure source differs from the other two

** Indicates a time point where only the largest and smallest values differ

***Indicates a time point where all three differ

This rate of 140 m^3/ha, which is 2.5 times the usual practice on the farm, shows a difference at every time point with raw manure always having less available inorganic N than digested or lagoon manure. After the initial time point, results for the raw manure are negative because there was more KCl-extractable N in the urea and soil controls than in the soil from the manure incubation. There were fewer differences at the low rate of manure application (28m^3/ha) and these differences were not consistent. At the 28m^3/ha rate, available N attributable to the lagoon manure source was significantly higher than for the other types (week 2), but by later in the incubation, N attributable to raw manure was significantly higher (week 8). Until 6 weeks, the 56 m^3/ha rate KCl-extractable N was greatest in the digested and lagoon samples, but by 8 weeks, extractable N from digested manure was lower than raw or lagoon manure. Generally, these results agreed with Pilar Bernal and Kirchmann's (1992) study, showing that anaerobically treated manure additions result in more N mineralization than raw manure.

Less extractable N was measured in the raw manure incubations because of greater N immobilization. Later in the incubations, in the 6th and 8th week, available N increased at the lower rate (28m^3/ha) for raw manure. At both the higher rates of manure application, raw manure was markedly lower in extractable N than digested or lagoon sources during the first two weeks. At the lower rate (28m^3/ha) this decrease was not observed. This could be because there were not enough available C added to trigger a decrease in extractable N, or the decrease may have occurred before the first sample was taken at two weeks and was not captured by the sampling times. Again, these incubations follow the pattern observed by Pilar Bernal and Kirchmann (1992) and Serna and Pomares (1991).

Although total C was scarcely different among the three manure types (raw: 400 g/kg, and digested and lagoon both 383 g/kg), there were significant differences in respired C (Figure 11). In these incubations, respired C attributable to raw manure was greater at every application rate and every time point except one, the final time point at 56 m^3/ha.

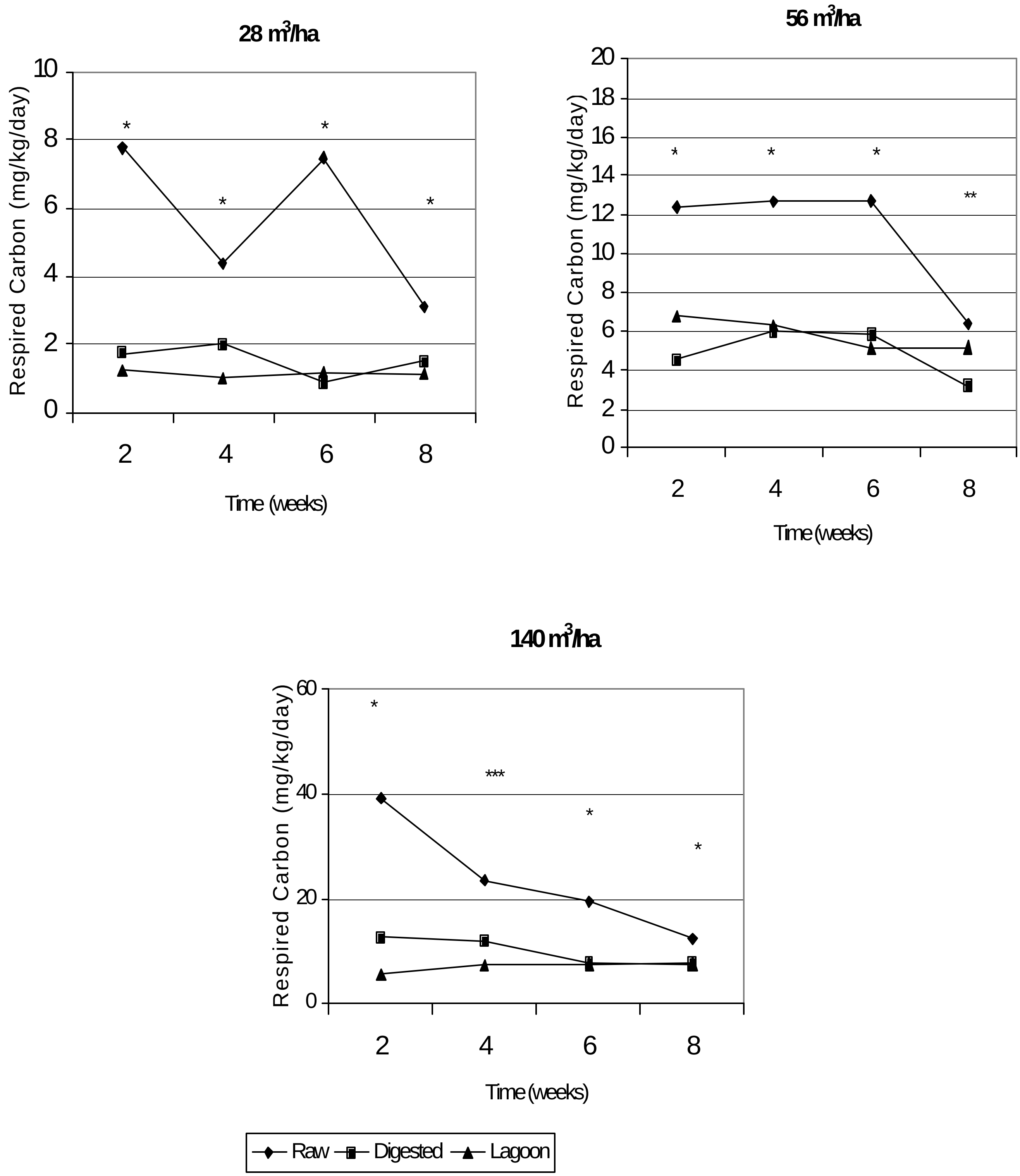


Figure 11. Net Respired Carbon Attributable to Manure Source by Application Rate during an 8 week Incubation

* Indicates a time point where one manure source differs from the other two

** Indicates a time point where only the largest and smallest values differ

***Indicates a time point where all three differ

The major difference between the manures tested in this study is the digestion process. This could account for the differences in mineralizable C and N. Digested and lagoon manure could have lower C values because the easily digestible C has been used by the microbes in the digester. This easily digestible C includes the volatile solids which cause odor. Petersen (1992) determined that even a small decrease in the volatile solids will reduce odor. Odor reduction is one of the benefits attributed to the digestion process. The raw manure has not gone through the digestion process; therefore the microbes have a more abundant source of decomposable C substrates and a higher respiration rate thus can immobilize N for longer periods of time.

Conclusions

Inherent soil variability and low nutrient status resulted in high coefficients of variation at this field site. This variability may have masked differences among the types of amendments applied. However, the low rates of N applied to our plots should have maximized the differences we observed. Therefore, our results suggest that digested manure produced equivalent yields to raw manure and inorganic fertilizer, as well as increased soil N over unfertilized areas. In terms of other soil quality parameters, digested manure was equal to raw manure and inorganic fertilizer in sustaining or increasing soil quality over the duration of this study.

While 8 week laboratory incubations did indicate that raw manure had less available N than either digested or lagoon stored manure, these differences were not observable in the field. Until late in the incubation, digested and lagoon manure released more available nitrogen than the raw manure. These differences were most dramatic at high rates of application and resulted from greater immobilization of N in the raw manure treatment. Analysis of the three manures by the University of Wisconsin directly out of the mixing pit, digester and lagoon also did not show any significant differences among the different types of manures. Further study at a site with less inherent variability and more replication might allow more consistent differences in nutrient sources to be observed.

The results of this study suggest that anaerobic digestion does not decrease manure fertilizer value or resulting productivity. Environmental risks or benefits also need to be considered, but such measures were beyond the scope of this study. A digester can benefit the farm financially from methane and heat production and odor reduction, and there was no loss in fertilizer value or soil quality from the digestion process at this site.

APPENDIX A

Effect of Fertilizer Type and Application Frequency on Microbial Biomass Carbon and Nitrogen, Haubenschild Farms, Princeton, MN 2002-2003

			Microbial Biomass Carbon				Microbial Biomass Nitrogen			
Date of Sampling			August 2002		August 2003		August 2002		August 2003	
Depth in cm			0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Field	Application Frequency	Nutrient Source	------mg/kg------				------mg/kg------			
Appel	Annual	Digested Manure	98.51	78.08	196.35	91.86	15.04	9.82	17.45	9.52
		Raw Manure	125.85	61.64	155.96	117.75	16.82	7.35	15.74	9.48
		Inorganic Fertilizer	107.04	51.66	141.95	110.68	15.80	6.91	17.71	13.62
		LSD (balanced)[1]	NS[2]	NS	52.73	NS	NS	2.36	NS	NS
Appel	Biennial	Digested Manure	–	–	103.50	95.39	--	--	13.73	8.15
		Raw Manure	–	–	189.15	118.79	--	--	19.17	10.28
		Inorganic Fertilizer	–	–	122.72	91.32	--	--	18.19	9.01
		LSD (balanced)	–	–	83.42	NS	--	--	NS	NS
Bruce	Annual	Digested Manure	74.82	49.15	91.75	67.27	16.39	7.57	17.17	10.61
		Raw Manure	100.19	80.34	137.59*	113.73*	18.04	10.34	19.91*	10.63
		Inorganic Fertilizer	68.47	63.52	95.29	66.40	16.77	8.84	13.96	8.62
		LSD (balanced)	NS	26.10	45.74	41.74	NS	NS	4.21	NS
		LSD (unbalanced)[3]	–	–	51.14	46.67	--	--	4.70	--
Bruce	Biennial	Digested Manure	94.88	31.05	94.29	67.66	16.35	6.77	14.86	10.37
		Raw Manure	51.24	51.93	96.19	66.26	15.05	7.82	12.71	9.43
		Inorganic Fertilizer	99.12	84.90	77.73	67.98	11.51	10.25	12.75	9.95
		LSD (balanced)	NS	NS	15.58	NS	NS	2.77	NS	NS
Lilac	Annual	Digested Manure	71.34	70.18	140.92	108.31	17.14	12.24	10.89	19.67
		Raw Manure	116.56	91.43	163.23	120.53	17.53	12.63	16.45	17.78
		Inorganic Fertilizer	65.41	70.63	68.50	104.21	10.30	12.36	10.92	17.88
		LSD (balanced)	NS	NS	NS	NS	NS	NS	NS	NS
Lilac	Biennial	Digested Manure	92.14	84.15	119.43	106.08	12.79	15.53	17.96	14.12
		Raw Manure	75.54	50.29	121.18	114.28	15.56	12.11	13.53	18.72
		Inorganic Fertilizer	101.21	63.97	108.48	103.42	15.55	12.14	8.70	17.16
		LSD (balanced)	17.70	22.47	NS	NS	NS	NS	8.24	NS

[1]LSD (balanced, $p < 0.1$) refers to the three preceding nutrient sources within the indicated application frequency ar

[2]N/S designates instances where results for the nutrient sources were not significantly different

[3] LSD (unbalanced, $p < 0.1$) refers to the three preceding nutrient sources within the indicated application frequency and field, where values were calculated by hand due to missing data points

* Category missing data point, so unbalanced LSD should be applied

APPENDIX B

Effect of Fertilizer Type and Application Frequency on PMN, Haubenschild Farms, Princeton, MN 2001-2003

			Potentially Mineralizable Nitrogen											
Date of Sampling			July 2001		August 2001		July 2002		August 2002		June 2003		August 2003	
Depth in cm			0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30	0-15	15-30
Field	Application Frequency	Nutrient Source	---mg/kg---											
Appel	Annual	Digested Manure	10.64	8.89	12.91	11.13	19.19	12.78	18.99	13.66	14.47	11.34	17.93	15.45
		Raw Manure	14.04	8.41	16.53	12.95	19.55	13.41	20.77	12.67	12.77	7.72	16.98	11.99
		Inorganic Fertilizer	14.39	9.81	14.44	10.97	18.21	11.98	19.30	11.31	30.95	6.72	21.62	14.09
		LSD (balanced)[1]	NS[2]	NS	3.45	NS	NS	NS	NS	2.17	NS	NS	NS	NS
Appel	Biennial	Digested Manure	--	–	--	--	--	--	--	–	14.83	9.78	13.53	8.51
		Raw Manure	--	–	--	--	--	--	--	–	14.32	9.67	19.90	10.47
		Inorganic Fertilizer	--	–	--	--	--	--	--	–	11.20	7.45	13.26	7.20
		LSD (balanced)	--	–	--	--	--	--	--	–	1.47	NS	6.58	NS
Bruce	Annual	Digested Manure	4.21	7.56	8.95	8.81	13.12	11.15	15.60	11.58	11.11	10.42	12.55	12.96
		Raw Manure	8.00	7.30	10.94	11.07	16.55	13.44	18.34	14.29	15.53*	9.90	15.70	21.69
		Inorganic Fertilizer	10.29	10.18	11.04	9.02	16.92	12.73	20.71	14.21	10.64	10.04	14.08	11.58
		LSD (balanced)	4.78	NS	NS	1.96	2.40	NS	4.53	NS	4.14	NS	NS	NS
		LSD (unbalanced)[3]	--	–	--	--	--	--	--	–	4.63	--	--	--
Bruce	Biennial	Digested Manure	--	–	--	--	15.12	10.26	17.36	10.83	13.03	19.93	18.16	12.09
		Raw Manure	--	–	--	--	13.23	10.27	14.91	10.72	11.21	11.05	14.40	10.49
		Inorganic Fertilizer	--	–	--	--	16.76	14.53	15.87	12.97	34.47	10.13	15.81	11.48
		LSD (balanced)	--	–	--	--	NS	3.86	NS	NS	NS	NS	NS	NS
Lilac	Annual	Digested Manure	5.38	10.47	10.86	11.31	20.00	20.64	19.34	13.91	17.07	11.28	8.87	17.09
		Raw Manure	7.23	9.11	8.00	9.99	22.00	20.88	21.14	19.12	16.18	14.42	13.67	14.33
		Inorganic Fertilizer	5.99	11.27	8.07	11.05	15.38	16.57	14.68	15.74	9.57	17.93	11.27	11.50
		LSD (balanced)	NS	NS	NS	NS	NS	NS	NS	4.64	NS	NS	NS	NS
Lilac	Biennial	Digested Manure	--	–	--	--	18.24	18.25	17.60	17.92	14.22	14.01	15.57	16.61
		Raw Manure	--	–	--	--	15.70	16.70	14.76	17.45	12.63	11.32	8.28	7.31
		Inorganic Fertilizer	--	–	--	--	19.99	17.84	18.24	16.40	13.28	8.52	15.46	11.59
		LSD (balanced)	--	–	--	--	NS	NS	NS	NS	NS	NS	NS	NS

[1] LSD (balanced, $p<0.1$) refers to the three preceding nutrient sources within the indicated application frequency and field

[2]NS designates instances where results for the nutrient sources were not significantly different

[3]LSD (unbalanced, $p<0.1$) refers to the three preceding nutrient sources within the indicated application frequency and field, where values were calculated by hand due to missing data points

* Category missing data point, so unbalanced LSD should be applied

APPENDIX C
Manure Nutrient Concentrations over Time, Haubencshild Farms, Princeton, MN

Sampling Date		10/2002	3/2003	4/2003	4/2003	5/2003	6/2003	7/2003	8/2003
Nutrient	Manure Type	---g/L---							
Nitrogen	Raw	3.99	3.12	5.07	3.22	3.26	2.79	3.15	3.39
	Digested	3.99	4.46	3.52	4.13	3.40	3.34	2.69	3.07
	Lagoon	2.67	–	--	3.76	–	2.90	3.03	3.03
Phosphorus	Raw	1.51	0.83	1.45	0.54	1.07	0.98	1.11	0.76
	Digested	1.40	1.05	0.61	0.61	0.83	0.81	0.81	0.55
	Lagoon	0.72	–	--	0.56	–	0.78	0.76	0.54
Potassium	Raw	4.55	2.64	5.82	2.94	3.44	3.26	3.88	3.72
	Digested	4.10	3.60	3.15	3.46	2.54	3.26	3.32	3.30
	Lagoon	3.41	–	--	3.31	–	3.05	3.45	3.25
Sulfur	Raw	0.36	0.37	0.50	0.37	0.38	0.36	0.42	0.49
	Digested	0.28	0.31	0.39	0.34	0.30	0.31	0.28	0.28
	Lagoon	0.21	–	--	0.34	–	0.31	0.31	0.36

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