Animal manure – reduced quality by anaerobic digestion?

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Abstract

Anaerobic digestion may reduce emissions of greenhouse gases, but we know little about its impact on soil fertility. Reduced concentrations of easily degradable C in the manure may imply less food for the soil fauna and microflora. A field experiment to study its effect on crop yields and soil characteristics, established in 2011, showed comparable yield levels in perennial ley over 3 years when digested slurry was compared with undigested slurry. Digestion had no influence on either soil nutrient concentrations or soil organic matter levels over the first 2 years. Application of high amounts of manure caused the death of both surface-dwelling and soil-living earthworms shortly after application, but the long-term effect of manure application seemed more positive, especially at low application levels. So far, we have observed only small differences in the effects of digested and undigested manure.

Introduction

By anaerobic digestion (AD) of manure, farmers may produce biogas to replace fossil fuels and reduce methane emission during storage. AD may also ease manure handling and reduce the content of animal pathogens and viable weed seeds. A reduced proportion of easily degradable carbon (C) in the digested manure may affect soil organic matter, fauna and microflora. Organic nitrogen (N) is mineralized during digestion, so that the proportion of mineral N is commonly higher in digestates than in untreated manure. Higher availability of N applied in manure may increase crop yields and possibly compensate for the organic C removed via AD. The effect of AD of animal manure is under study in the project "SoilEffects". We present results from the first three growing seasons, 2011-2013, to discuss whether AD of manure affects soil characteristics and plant yields.

Material and methods

A biogas plant was established in 2010 at Tingvoll research farm, NW Norway, for AD of the slurry from 25 organically managed dairy cows. Yields and soil characteristics were studied in a field experiment with different manure application in two cropping systems: 1) arable crops (no legumes) with annual ploughing and 2) perennial grass-clover ley established in 2010. The crops in the arable system were oats (2011), ryegrass (2012) and spring wheat (2013). Low and high application levels of digested manure (D) and untreated manure (U) were compared, with total levels of 85 (low, L) and 170 (high, H) kg total N ha^{-1} yr^{-1} applied to arable crops, and 110 (L) and 220 (H) kg to perennial ley. No manure was applied in the control treatment. Each cropping system had four replicate blocks. Within each block, the treatments were randomly distributed on experimental plots (3 m x 8 m). The manure was diluted with water to < 5 % dry matter (DM). In arable crops, the manure was incorporated using a rake in 2011 and 2012. In 2013, the manure was incorporated with a horizontal rotavator. From each plot, a composite sample of 10 soil cores was taken in spring 2011 (before starting the experiment) and in spring 2013 (before manure application). The soil is a loamy sand, with low extractable phosphorus (P) status (< 40 mg P-AL kg^{-1} dry soil) and very high acid-soluble potassium (K) status (>1200 mg K-HNO_3 kg^{-1} dry soil) (Table 3). P-AL values in six of the 20 soil samples in the arable cropping system were below the detection limit (< 20 mg) in 2011, but set to 15 mg to facilitate statistical analysis. Immediately after manure application in spring 2013, the numbers of dead earthworms on the soil surface were recorded, and in autumn 2013, earthworms were sorted from soil cubes (8 l).

Statistical analyses were performed using Minitab 16 and SAS Statistical Software. A general linear model was used to test the effect of treatments on yield levels, and Tukey t-test at the 5 % level to compare the

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mean values of treatments. For comparisons of soil analyses in 2011 and 2013, paired t-tests were performed.

Results

Yields

In the grass system, the yield levels were strongly increased by manure application (Table 1). Digested manure gave the same yields as untreated manure. The yields declined over time in the control treatment, and hence the relative differences between the fertilized treatments and the control increased. In the fertilized treatments, the yield levels increased from 2011 to 2012. In treatments with low levels of manure, this seemed to continue also in 2013, whereas in the treatments with high levels, the total yields were slightly lower in 2013 than in 2012 (Table 1).

Table 1: Total and relative yields of ley (sum of two cuttings) in 2011-13, tonnes of dry matter ha^{-1} by different application of manures. N= no manure (control), U= untreated manure, D= anaerobically digested manure, L = low level of manure, H = high level. Statistically significant differences within year (P<0.05) are suffixed as a, b and c.

Treatment	2011	2011rel.	2012	2012 rel.	2013	2013 rel.
N	6.61 a	100	5.42 a	100	4.62 a	100
UL	8.05 ab	122	9.03 b	167	9.11 b	197
UH	8.78 b	133	10.45 bc	193	10.23 b	221
DL	8.19 b	124	8.95 b	165	9.28 b	201
DH	8.44 b	128	11.56 c	213	10.58 b	228

In the arable system, the apparent yield increase due to manure application was not statistically significant in any year, but a tendency (P = 0.095) was found in 2013 (Table 2). However, differences in growth characteristics such as straw length and plant colour were clearly visible between treatment plots during the growing season in 2011, and straw length was significantly increased by the DH treatment (Table 2).

Table 2. Total and relative yields of arable crops in each year 2011-13, tonnes of dry matter ha^{-1}, sum of straw + grain in 2011 and 2013, sum of two cuts of ryegrass 2012. Manure treatments and suffixed letters as in Table 1. The column "2011 cm" shows the mean length of oats straw in 2011.

Treatm.	2011	2011rel.	2011cm	2012	2012 rel.	2013	2013 rel.
N	5.35 a	100	65 a	2.23 a	100	2.98 a	100
UL	5.80 a	108	69 a	2.56 a	115	3.22 a	108
UH	5.98 a	112	72 ab	2.75 a	123	3.83 a	128
DL	5.60 a	105	71 ab	2.57 a	115	3.80 a	128
DH	6.11 a	114	78 b	2.64 a	118	4.00 a	134

Yield levels in 2012 were generally very low due to poor establishment of fodder rape, which had to be replaced by a late-sown ryegrass crop. Emissions of N_2O were measured in this system in 2012, showing higher values than former measurements in ley at Tingvoll. This may indicate that the manure was not sufficiently well incorporated, and may partly account for the lack of fertilization effect in both 2011 and 2012. In 2013, when a horizontal rotary harrow was used for combined soil tillage and incorporation of manure, the yield effects were larger (Table 2). Furthermore, a clearly better yield effect was obtained for the digested manure in 2013. Comparing the means of both digested manure treatments with the mean of the untreated manure treatments and the control, close to significant differences were obtained (P= 0.056) and the mean yields were D = 3.9(a), U = 3.5(ab) and N = 3.0(b) tonnes DM ha^{-1}.

Soil characteristics

In spite of the relatively short experimental period, statistically significant changes in some soil properties were found (Table 3). The soil content of organic matter (SOM), shown as ignition loss, decreased in the arable system. This result was expected, since soil tillage tends to decrease SOM. In the grass system, with much higher initial values of SOM, the values seemed to increase in both treatments with high manure application, and to decrease in the other treatments, but the differences between 2011 and 2013 were not statistically significant in this cropping system. For pH, a slight increase was found in most treatments (Table 3). This may have been attributable to wetter soil conditions at soil sampling in 2013, causing pH increase. For extractable P, no decrease was found in the control treatments, where this could be expected since there was no replacement of the plant nutrients removed. However, as the soil has a high content of SOM, there were probably sufficient P reserves. In the fertilized treatments in the grass system, the levels of applied manure increased the soil P concentrations, especially at the high application levels. In the arable system, less P was removed from the soil due to generally low yield levels. Hence, larger increases in extractable P could have been expected. However, the P status of the arable system soil system was generally lower (Table 3), and more P seemed then to be required to increase the P-AL level. For acid-soluble K, significant decreases were found in many treatments, in spite of manure application. Yield levels were high in the grass system, and grass-clover leys extract a lot of K from the soil. Also in the arable system, with much lower yields, significant decreases in soil K were found.

Soil aggregate size distribution and aggregate stability were measured after sampling in spring 2013. None of the size fractions were affected significantly by manure application. The aggregate stability was high, especially on the grass plots (mean 93%), due to their high content of soil organic matter and the known positive effect of grass on soil stability. On these plots, there was no significant effect of the manure applications during the previous two years. On the arable plots, where the stability was ca. 85% on control plots, significant (P=0.02) increases of stability by 2-3 %-units were found with all four manure treatments.

Table 3. Selected soil characteristics (0-20 cm depth) at the start of the experiment in spring 2011, mean values of four replicate plots per treatment and crop, compared to values in spring 2013 after two years of manure application. Phosphorus (P) and potassium (K) concentrations in mg kg^{-1} dry soil. Statistically valid changes and tendencies (by paired t-test) = (*) for P < 0.1, * for P < 0.05, ** for P < 0.01.

		Ignition loss %		pH		Extractable P		Acid-soluble K	
	Tr.	2011	2013	-11	2013	2011	2013	2011	2013
GRASS	N	10.83	10.18	5.80	5.98(*)	28.3	30.0	112	101
	UL	10.65	10.28	5.75	6.03*	26.8	35.0*	128	113(*)
	UH	11.90	12.33	5.85	6.18*	30.5	43.3**	126	108
	DL	11.25	10.50	5.85	6.08**	26.5	32.5(*)	131	106**
	DH	12.05	12.33	5.83	6.10*	31.3	40.0*	115	103*
ARABLE	N	6.73	6.38	5.83	5.95*	27.5	25.8	180	155 (*)
	UL	6.28	5.53*	5.90	5.95	21.8	24.3	178	155*
	UH	6.48	5.78*	5.83	5.98*	21.3	26.3(*)	173	165
	DL	7.05	6.33(*)	5.93	6.08	21.3	25.3*	170	150*
	DH	6.35	6.05	5.88	6.08*	23.8	29.3(*)	175	160

Earthworms

In the ley, many earthworms came to the surface and died shortly after manure application. In 2013, 19 dead worms m^{-2} were found in UH, 11 in DH, 4 in DL, 2 in UL and 0 in N. Dead worms belonged to both surface dwelling species (*Lumbricus rubellus, L. terrestris*) and more soil dwelling species (*Aporrectodea caliginosa, A.rosea)*. In the autumn of 2013, the average earthworm density without manure application was 150 m^{-2}. The highest density (244 individuals m^{-2}) was found with application of high amounts of digested slurry. With application of low amounts of both types of manure it was also well above the control treatment (200 m^{-2} for UL and 181 for DL). The lowest value was found with high amounts of undigested slurry (119 m^{-2}). However, as the variation was high, none of the latter figures differed significantly.

Conclusions

In perennial ley, both untreated and digested manure increased the yield levels significantly and to a similar extent. In arable crops, when the manure was thoroughly incorporated into the soil there was a tendency for better yields to be obtained with digested manure. Arable cropping decreased the soil organic matter content (SOM). High manure application caused death of many earthworms. More work is required to conclude whether anaerobic digestion gives manure of poorer quality for organic farming systems, but its short-term effects seem so far to have been minor.