Application of Anaerobically Digested Dairy Slurry: effectiveness of perforated injector disk

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Summary

In this paper, problems affecting anaerobically digested dairy slurry are discussed. Among such problems, fertility adjustment, soil compaction by heavy slurry tankers and the reduction of soil-disk (injector machinery) resistance are discussed in detail. The reduction of soil-disk resistance and its impact on reducing the energy requirements of slurry spreader and injector implements could be achieved through experimentation conducted for this study. Perforated and solid disk units were used in the experimentation to compare soil-disk and motion resistance. Soil-disk resistance of the perforated disk was 21 % less than that of the solid disk. Motion resistance of the gauge wheel of the perforated disk unit was 9.7 % more than that of the solid disk unit. Total resistance (soil-disk resistance and motion resistance of the gauge wheel) of the perforated disk unit was 4.5 % less than the solid disk.

Keywords: spreader, injector, motion resistance, resistance, soil compaction, biogas plant

Introduction

Biogas plants have been constructed to treat animal effluent, especially that of dairy cows. The biogas plants obtain methane through anaerobic fermentation and use it as fuel for electricity and heat generation using cogeneration systems. However, almost the same amount of residue digested slurry as initial slurry charged to the digester of the plant, is discharged after digestion. Anaerobically digested dairy slurry still contains nitrogen, phosphorus, potassium and trace elements as major fertilizer elements. When the slurry application systems to upland and grassland fields are better established and simplified for ease of use by farmers, the total amount of chemical fertilizer can be reduced.

Several systems for animal effluent application with slurry tankers and spreaders, or injectors, have been introduced in Hokkaido, Japan. However, to ensure that the intended amount of nutrients in slurry is applied to a given field, it is important to know the amounts of residue NPK in the soil beforehand. It is also important that suitable machinery is selected to ensure accurate slurry application.

In this paper, several problems concerning the application of anaerobically digested slurry are discussed. As soil cutting resistance using shallow injector disks could be reduced by applying newly engineered disk designs, experiments were conducted with solid and perforated disks.

Slurry spreading systems

Chambers, et al. (2001) recommended selecting the right handling and spreading system to ensure that the intended amount of nutrients from slurry have been applied to the crop. Four main types of slurry distribution systems are explained by Chambers, et al. (2001) as follows:

Broadcast spreader (splash plate or nozzles)

The slurry is forced under pressure through a nozzle, often onto an inclined plate to increase the spread sideways.

Band spreader

The spreader boom has a number of hoses connected to it, distributing the slurry close to ground in strips or bands. It is fed with slurry from a single pipe, thus relying on the pressure at each of the hose outlets to provide an even distribution. Advanced systems use rotary distributors to proportion the slurry evenly to each outlet.

Trailing shoe spreader

This has a configuration similar to the band spreader with a shoe added to each hose allowing the slurry to be deposited under the crop canopy onto the soil. It is also possible to spread in growing crops without contaminating the crops.

Injector

Slurry is injected under the soil surface. There are various types of injectors that basically fall into one of two categories: the open slot shallow injector category for up to 50 mm depths and the deep injector for depths greater than 150 mm.

Technological problems of slurry application

Fertility adjustment of slurry for crop production

The Department of Agriculture of Hokkaido Prefecture published the “Hokkaido Prefecture Fertilizer Application Guide” (2002) that divides Hokkaido into eighteen areas meteorologically, topographically and by soil type; and suggests the amount of N, P_2O_5, K_2O necessary for optimum crop production of several crops. For example, the N, P_2O_5, K_2O requirements for table potatoes in central Tokachi are 80, 200 and 120 kg/ha (hectare), respectively. However, the nutrient content of digested slurry of N, P and K is about 0.3, 0.1

and 0.3 % to slurry weight, respectively. When digested slurry is applied to a certain crop, it has to be adjusted using chemical fertilizers to ensure the optimum balance of chemicals is applied according to the “Hokkaido Prefecture Fertilizer Application Guide”. It is very important to harvest the target yield. A mixing device for slurry and chemical fertilizer is expected to eventually be developed, but no such device exists currently.

Soil compaction

A trailer type slurry tanker of 12,000 L capacity has been introduced on the market. A tanker with a slurry injector or spreader is quite heavy when the tank is filled up with slurry. When this type of tanker is trailered behind a tractor using a drawbar supported by tandem axles, the static load on the front and rear axles of the tanker and on the drawbar is about 65, 72 and 11 kN (6.7, 7.4 and 1.1 t), respectively (Nishizaki, 2000). If the tanker has one axle, the static load on the axle is 137 kN. Soil compaction by slurry tanker tires may be severe.

Soil compaction affects the soil physical environment for crop production in agriculture (Gill and Vanden Berg, 1967). Excessive soil compaction reduces infiltration of water into soil thereby increasing the potential for runoff and erosion. Excessive soil compaction also prevents crop roots from extending into soil for water and nutrients. Soil compaction research has been conducted mainly for agriculture tractor drive tires, but a study on much heavier vehicle tires should be conducted to reduce soil compaction by slurry tankers.

Soil-disk (injector machine) resistance

Broadcast spreaders (splash plate or nozzle) have been used for slurry application in Hokkaido. Chambers, et al. (2001) pointed out that the use of broadcast spreaders cause odor diffusion, ammonia emission, slurry spread on plant leaf and so on. These problems can be avoided by the use of slurry injectors. However, Chambers, et al. (2001) also pointed out slurry injectors cause large soil tillage resistance. This means that the operation of slurry injectors requires more fossil fuel, though they provide an advantage for crops and lessen environmental pollution from chemical fertilizers. To reduce the fuel consumption of operating a slurry injector by minimizing the cutting resistance of the injector disk is considered an important objective.

Soil-disk resistance is thought to consist of the resistance which is incurred in cutting the soil at the front side of the disk and friction between the soil and disk sides. Reduction of soil cutting resistance is thought to be very difficult. However, resistance from the friction of the contact area between the soil and disk sides may be decreased by engineering a different disk design. From this engineering aspect, a perforated disk was thought to be more effective in reducing friction.

Reduction of soil-machine resistance of slurry shallow injector

Factors of soil-machine resistance

Figure 1 shows the schematic diagrams of external forces acting on a tanker and an open slot injector unit of a gauge wheel and a slot cut disk for use on grassland. The injector is equipped with twenty to thirty units depending on the injector width (JOSKIN, 1999). The gauge wheel controls the depth of an open slot disk as it comes in contact with the grassland surface. A part of the vertical load of the injector unit is applied to the gauge wheel as the reaction of the dynamic load R_2, and motion resistance f_2 is produced. The resistance between these parts and grass is produced. For this study, the magnitude of these resistances f_2 and f_3, shown in Fig. 1, are measured.

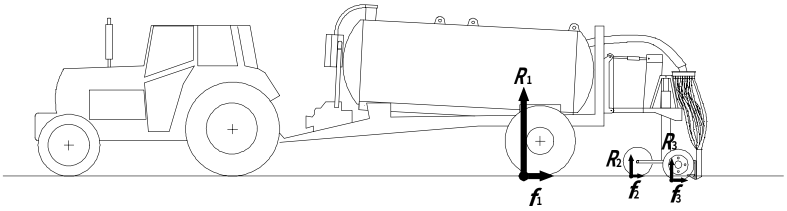

Figure 1 The schematic diagram of external forces acting on a shallow injector and tanker.

Methods

Figure 2 shows the circular disks of the slurry injector used in the experiments. A shallow injector for grassland is normally equipped with a solid disk (Fig. 2a.) to open a slot at the soil surface.

In order to reduce the friction between the disk side and soil, a newly designed perforated disk was made (Fig. 2b.). A part of the disk surface was perforated to minimize the disk side-soil contact area. These two types of disks were used for the experiments. Both disks were 3 mm thick and 300 mm in diameter.

Figure 3 shows the experimental unit of an open slot injector. Experiments were conducted on an

a. Solid disk *b. Perforated disk*

Figure 2 Open slot disks used for experiments

Figure 3 Experimental unit of shallow injector

indoor soil bin containing sandy clay. The composition of the sandy clay was 57.0 % sand, 12.0 % silt and 31.0 % clay. Preparation of the soil for the experiments was done by rotary tilling, compacting and leveling after adding adequate water for desired moisture content. Moisture content of the soil was about 12 % at wet base. Average cone index of the soil at a 10 cm depth was 374 kPa. The forward velocity of the tested device was adjusted to 0.17m/s. Cutting depth of the disk was set at 4, 6 and 8 cm.

Results

Figure 4 shows the measured cutting resistance of the disk f_3. The absolute value of cutting resistance of a disk increased with increasing cutting depth. The cutting resistances of the perforated disk were smaller than those of the solid disk at each cutting depth. Table 1 shows disk cutting resistance and the ratio of the resistance decrease of perforated disk to solid disk resistance at each cutting depth. The average decrease was 21.4 %. It was found that disk perforation is effective in reducing the cutting resistance.

Figure 5 shows the motion resistance of a gauge wheel f_2. The absolute values of motion resistance of a gauge wheel decreased with increasing cutting depth of the disk. The motion resistances of the gauge wheel of the perforated disk unit are larger than those of the solid disk at each cutting depth. Table 2 shows the motion resistance and the ratio of the resistance increase of a gauge wheel with a perforated disk to the resistance with a solid disk at each cutting depth. The average increase in the ratio was 9.69%. This is caused by the increase of the reaction of the dynamic load to the gauge wheel as shown in Figure 6. The interaction between the injector unit and soil is explained by the phenomena that the reduced vertical load to the wheel transferred to the disk (Kishimoto et al., 2002).

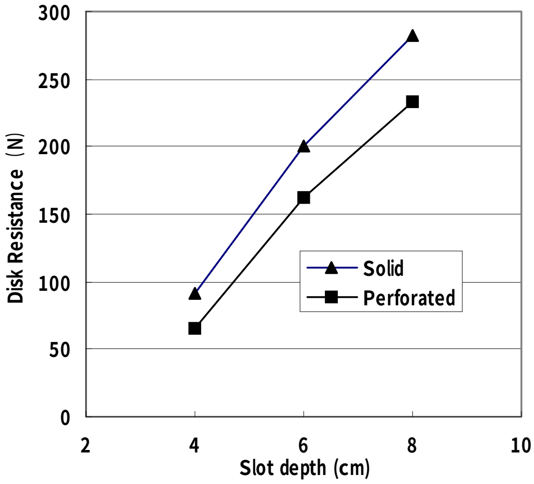

Figure 4 Resistance and slot depth

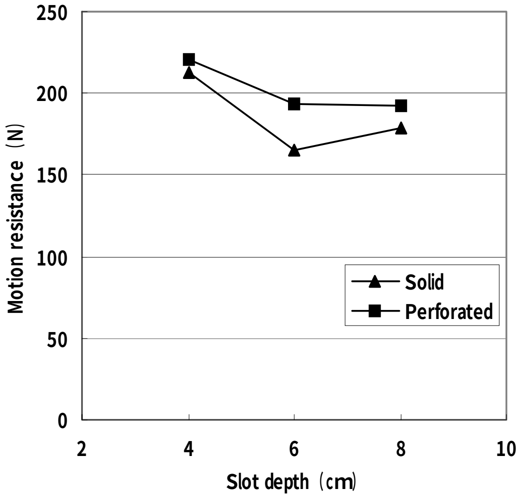

Figure 5 Relationship between cutting depth and gauge wheel motion resistance.

Table 1 Disk cutting resistance and the ratio of the decrease in resistance of the perforated disk compared to the solid disk resistance

Cutting depth (mm)	Solid disk (N)	Perforated disk (N)	Decrease (%)
40	91.4	66.1	27.7
60	200	162	19.1
80	282	233	17.5

From these results, total resistance (soil-disk resistance and the motion resistance of the gauge wheel) was considered to be less for the perforated disk unit (a cutting disk and a gauge wheel) than for the solid disk unit. The perforated disk unit produced less cutting resistance and more motion resistance than that of a solid disk unit. Figure 7 shows total resistance (cutting resistance of the disk and motion resistance of the gauge wheel) acting on the disk unit. The absolute values of total resistance of both perforated and soil disk units increased with an increasing cutting depth of the disk. However, the total resistances of the perforated disk unit were smaller than those of the solid disk at each cutting depth. Table 3 shows total resistance and the ratio of the resistance decrease of the perforated disk unit to the total resistance of the solid disk unit at each cutting depth. The average decrease ratio was 4.5 %. It was also found that disk perforation is effective in reducing total resistance.

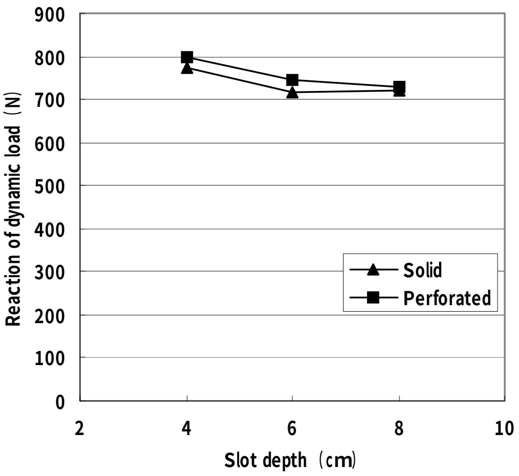

Figure 6 Relationship between cutting depth and reaction of dynamic load of gauge wheel motion

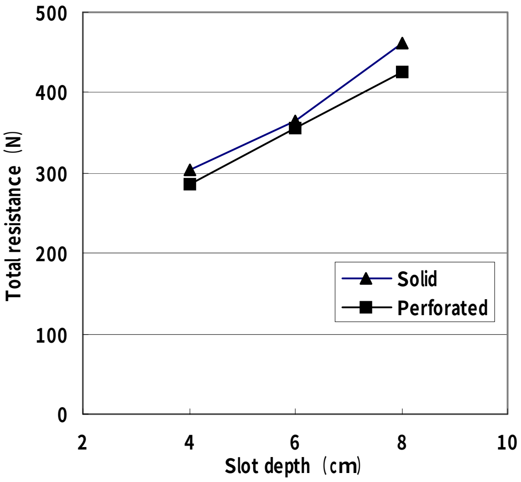

Figure 7 Relationship between disk cutting depth and total resistance

Table 2 Gauge wheel motion resistance and the ratio of the resistance increase of a gauge wheel with a perforated disk to the resistance with a solid disk at each cutting depth

Cutting depth (mm)	Solid disk (N)	Perforated disk (N)	Increase ratio (%)
40	213	221	3.63
60	165	194	17.8
80	179	193	7.66

Table 3　Total resistance and ratio of the resistance decrease of perforated disk unit to the total resistance of solid disk unit

Cutting depth (mm)	Solid disk (N)	Perforated disk (N)	Decrease ratio (%)
40	304	287	5.77
60	365	356	2.45
80	461	425	5.31

Conclusions

Application technology of anaerobically digested dairy slurry and its problems were discussed. In order to reduce the energy requirements of an open slot shallow injector, experiments were conducted with perforated and solid disk units to compare respective soil-disk and motion resistance.　The following conclusions were drawn.

1. Problems concerning fertility adjustment, soil compaction by heavy slurry tankers and the reduction of soil-injector resistance could be solved.
2. The absolute value of soil-disk resistance increased with an increase in cutting depth of the disk.　The total resistance of a perforated disk was less than that of a solid disk at each cutting depth.　The average difference was 21 %.
3. The absolute values of motion resistance of a gauge wheel decreased with increasing cutting depth of the disk.　The motion resistance of the gauge wheel of the perforated disk unit was greater than that of the solid disk at each cutting depth.　The average increase was 9.7 %.
4. The absolute values of total resistance of both perforated and soil disk units increased with increasing cutting depth of the disks.　However, the total resistance of the perforated disk unit was smaller than that of the solid disk at each cutting depth.　The average decrease was 4.5 %.
5. Disk perforation was found to be effective to reduce total resistance.

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