# Physical characterisation of animal manure.

Caractérisation physique du fumier.

**F. Thirion, F. Chabot, D. Andeler**
Cemagref Domaine des Palaquins - 03150 MONTOLDRE. France
Phone 33 (0)4 70 45 03 12 FAX 33 (0)4 70 45 19 46
e-mail francois.thirion@cemagref.fr

## Abstract

*The great variability of animal manure characteristics is due to the large diversity of livestock, storage type and handling equipment. The performance of a spreader is directly related to the physical properties of the material being spread out. When testing a spreader or researching spreading techniques, it is necessary to know the main physical characteristics of the manure.*

*The Swedish Institute of Agricultural Engineering has already developed a characterisation method. The implementation of their method has highlighted the necessity of increasing the number of factors measured and selecting equipment that may be used easily in the field. Cemagref have designed and tested measuring equipment specific for this purpose. A combination of 6 measurements has been set up for each heap of manure :*

*. Bulk density : weight of a bucket.*
*. Cohesion : use of a penetrometer.*
*. Shear stress resistance : use of a scissometer.*
*. Dry matter content : use of an oven.*
*. Straw content.*
*. Friction coefficient : use of an inclined plane.*

*These measurements have been carried out on 25 different types of manure. An heterogeneity coefficient has been determined based on several points of the graph obtained with the penetrometer at depths from 25 centimetres to 60 centimetres below the surface. Results were then compared to determine the main characteristics of each type of manure.*

*To confirm the usefulness of these measurements we analysed the relationship between these measures and the performance of the spreader. Three main relationships have been verified :*

*. density and discharge rate,*
*. shear stress resistance and drive torque,*

*. heterogeneity and spreading precision.*

*<u>Keywords</u> : manure, spreader, density, heterogeneity.*

## Résumé

La structure des fuimers présente de grandes variations en raison de la diversité des animaux, des stockages et des moyens de manutention. Les performances des épandeurs de fumier dépendent des propriétés du produit épandu. Il est donc nécessaire pour le Cemagref de déterminer les principales propriétés physiques du fumier lors des essais d'épandeur ou en vue de recherches sur l'épandage.

Le « Swedish Institute of Agricultural Engineering » a défini une méthode de caractérisation. La mise en oeuvre de cette méthode nous a montré le besoin d'augmenter le nombre de critères à mesurer et de choisir des moyens de mesure utilisables au champ. Nous avons défini et testé des appareils de mesure spécifiques. Un ensemble de 6 mesures a été retenu pour chaque tas de fumier :

. Densité : pesée de seaux.
. Cohésion : utilisation du pénétromètre.
. Résistance au cisaillement : utilisation du scissomètre.
. Taux de matière sèche : séchage à l'étuve.
. Richesse en paille.
. Coefficient de frottement : plan incliné.

Ces mesures ont été effectuées sur 25 fumiers différents. Nous avons défini un coefficient d'hétérogénéité, à partir des courbes du pénétromètre sur une profondeur de 20 à 65 cm. Les résultats ont été comparés afin de dégager les propriétés générales des types de fumier correspondants.

Pour justifier l'intérêt de ces mesures de caractérisation, nous avons cherché leur relation avec les performances d'un épandeur. Trois relations principales ont fait l'objet de vérifications :

. densité et débit,
. résistance au cisaillement et couple d'entraînement,
. hétérogénéité et précision d'épandage.

<u>Mots-clés</u> : fumier, épandeur, densité, hétérogénéité.

## 1 Introduction

The physical characteristics of solid manure cannot be defined simply according to its origin. Many factors may impact on these characteristics: for example, in the same shed, the density may vary from 400 kg/m$^3$ where the cattle is used to rest, to 700 kg/m$^3$ where the movement of cattle has compacted the manure.

This paper will describe a method for physical characterisation of solid animal manure. Cemagref wants to develop methods for testing manure spreaders and also wants to improve the working of machines. An agricultural machine has several components that work together as a system in order for the machine to perform in the intended manner. The manure spreader has to meter the manure quantity and to spread it in an even flow on a longitudinal way than as well as on a transversal way. Each function depends on the manure characteristics in a way that we are not able to quantify now.

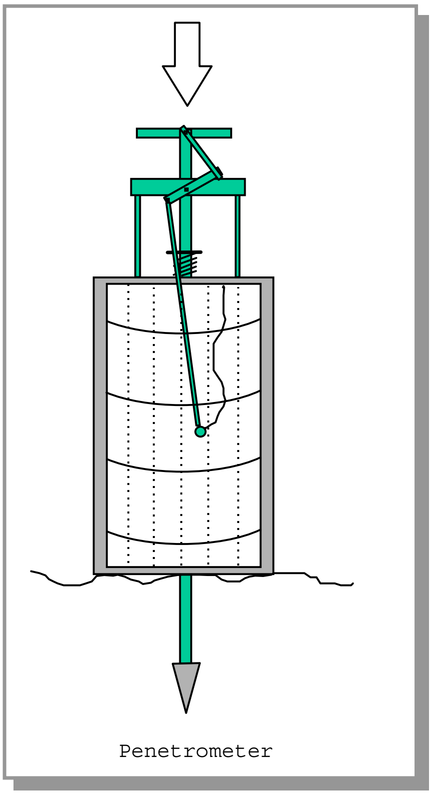
The Swedish Institute of Agricultural Engineering has already developed a method of manure characterisation, mainly for equipment testing purposes. We encountered several difficulties when we wanted to implement these methods. These methods have actually been set up in a research institute where large facilities are available for handling the manure. The handling equipment that we use in our institute is not reliable for this purpose, and for example it was not possible to fill up a characterisation box of 1 m$^3$ with this equipment. Another point is that the manure seems to be different under Swedish or French conditions. Under French conditions, straw is widely used in sheds, and it appears that this straw will widely change the physical properties of the manure. For example we intend to verify that manure density is connected to straw content, whereas under Swedish conditions it has been verified that manure density is mainly related to dry matter content.

Six tests have been defined for each manure heap, and tests have been carried out on the farms except for the dry matter content measurement which has needed samples to be brought back to the institute. It was then necessary to investigate whether the performances of the manure spreader are related to the manure physical characteristics. It is sure that the discharge rate is connected with density of the manure, as the delivery principle is based on the volume of the manure that has to be spread. Physical characteristics may also interfere with evenness of the spreading and power needed to work out the machine. These data are necessary when testing spreaders or implementing research on spreading techniques.

## 2. Definition of characterisation tests

### 2.1 Normal stress measurement

Penetrometers were used for this purpose. A penetrometer is an equipment usually fitted for measuring the soil cohesion. A conical tip is driven into the soil and the strength is measured either by a pressure gauge or by the length of a spring. We have selected the mechanical principle and used a set of 2 tips with a diameter larger than the one originally fitted. A pencil is fitted on this equipment in order to draw a continuous graph which indicates the value of the normal stress at each depth in the manure. The main advantage of this measurement is the ability to get data of physical characteristics inside the manure heap and also to get easily a large amount of data that may be analysed.



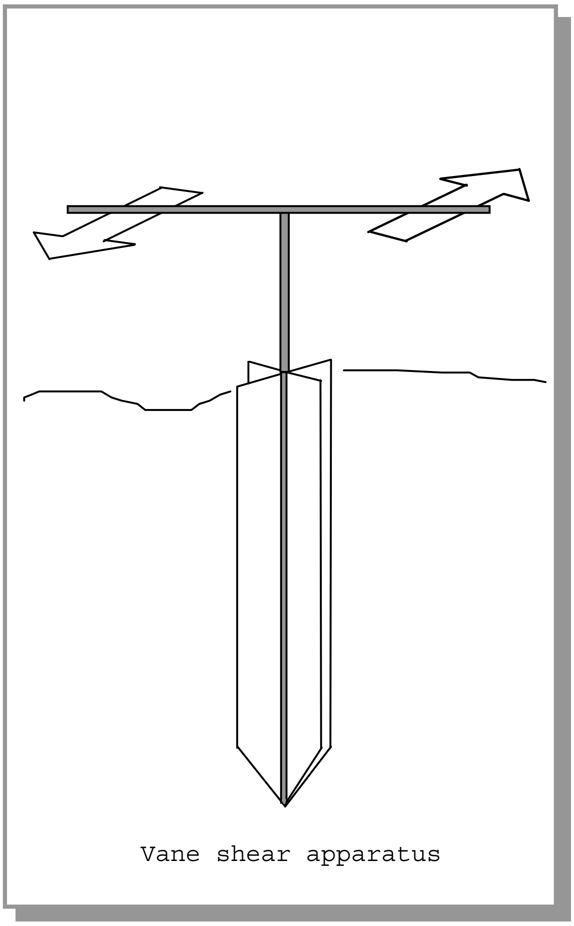

Normal stress: $\sigma = \frac{F}{S} = \frac{F}{\Pi R^2}$

F = Force ; S = Surface

**2.2. Measurement of shear stress**

We have selected a shear vane apparatus. This equipment does not require excavation. Once driven into the manure by a hammer, the rotation causes shear of manure along the surface which is generated by the vanes. The torque which is necessary to rotate the device is measured by a torque wrench.

Sheared area: $S = 2\Pi rh$ ( we consider that a cylinder of manure is sheared from the manure kept inside the system.)




Torque: M Shear stress: $\tau = \dfrac{M}{R.2\Pi rh}$

*M* = Torque. *R* = Torque application radius. *r* = Shear radius

**2.3 Measurement of bulk density**

The main problem in measuring bulk density is to define the conditions of measurement. At first we intended to define density of manure inside the heap. For this purpose a volume of manure inside the heap was separated by sheets of metal driven into the manure. By this way, we could determine a volume of manure and we dug out this manure to weigh it. It is also possible to separate a volume by the mean of the tractor loader. This volume is measured and the manure is loaded in a spreader and weighed.

It is easier to measure the weight of the manure after having handled it. Swedish method needs to fill up a characterisation box of approximately 1 $m^3$ volume, with the tractor loader. The purpose of this is to get similar conditions when using the characterisation box or when using a spreader. We tried also to fill up this box by hand with a fork. The results of these two measurements will depend on the way of filling the box.

Another way of measuring the bulk density is to fill up the spreader and weigh it. Main difficulty is to know the volume of the spreader, as the shape of the machine may be complicated. This way of measurement gives certainly the most interesting information when we want to study the performance of the spreader.

We selected another measurement for our field test. We fill up a bucket by hand and let it fall 3 times from 30 cm high in order to get similar compaction. We fill it up again.

Example: we analysed a 35 tons batch of manure:

| method of measurement | density |
|---|---|
| separation of 1.8 $m^3$ | 944 kg/ $m^3$ |
| separation of 3.6 $m^3$ | 798 kg/ $m^3$ |
| separation of 6.2 $m^3$ | 795 kg/ $m^3$ |
| 1 $m^3$ box filled by hand | 405 kg/ $m^3$ |
| 1 $m^3$ box filled by hand + compressing | 650 kg/ $m^3$ |
| manure in the spreader (7 $m^3$) | 450 to 650 kg/ $m^3$ |

It appears that the density variability is great in the same batch. When building this heap by means of a tractor loader, the farmer has created blocks of manure of high density separated by low density spaces. When handling the manure by hand the volume increases and the density decreases in a range of approximately 50%. When handling the manure by a tractor loader, the density depends on the way this implement is used and the density has been observed from 55% to 80 % of the manure density in the heap.

When measuring the density with buckets we observe also a large range of results. The expansion which is created by this method is similar with the one obtained by tractor loader. This value may be used to compare several types of manure, but not to know what will be the density inside the manure spreader. The measurement is repeated 4 times.

**2.4 Friction coefficient**

A sample of manure is placed on a plane surface which is slowly inclined. When the manure slips, the angle is measured. The purpose of this measurement is to verify whether the strength used to push the manure inside the spreader is connected to the friction coefficient. Actually this strength depends on 2 factors: the friction between the manure and the floor of the spreader, and the resistance of the manure being dislocated: The moving floor of the spreader acts on the manure in order to obtain a good dislocation by the beaters acting rearwards.

### 2.5 Straw content

It was not possible to define a method for direct measurement of the straw content. In order to get an indication concerning this factor, we decided to measure the length of 40 pieces of straw. The main advantage of this method is that it does not take account of small pieces of straw, as small parts of straw do not seem to modify the physical characteristics of the manure. Long pieces of straw increase the volume of the manure and reduce the density. Straw is also increasing the resistance to dislocation. For these reasons, we have chosen this particular measurement which appeared easy to do.

### 2.6 Dry matter content

Samples of manure are dried in an oven during 24 hours at a temperature of 120 °C. The decrease of weight is due to water evaporation. The dry matter content is the ratio water content/ wet weight. Under Swedish conditions, dry matter content appeared to be an important factor.

## 3. Results of measurements

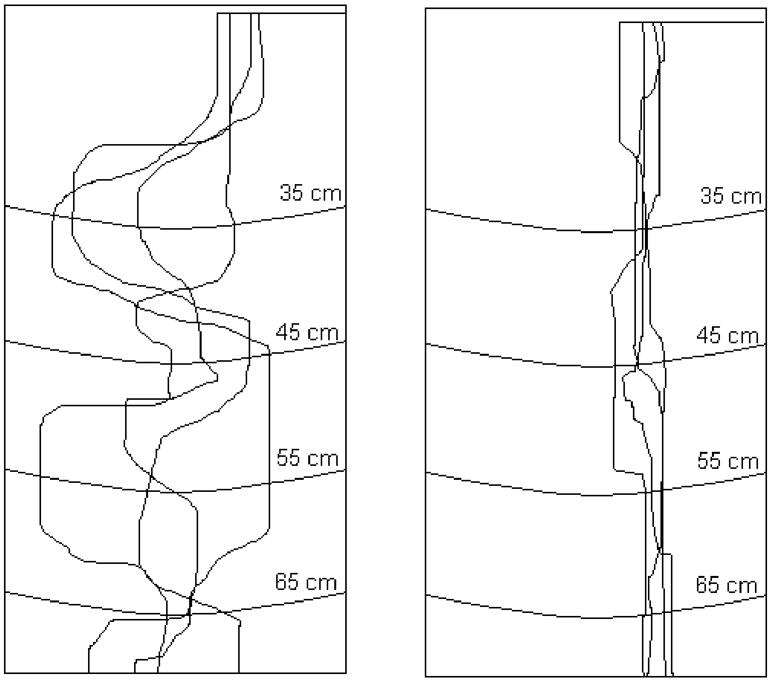
In 1997, 25 sets of measurements have been worked out in French farms around Cemagref. All the data was collected and analysed afterwards.

### 3.1 Normal stress

The normal stress appeared to vary from 0.14 MPa (1.4 bar) to more than 1.6 MPa (16 bar). The low resistances were met in compost, old manure. The high resistances were met inside heaps built by mean of a mechanical elevator or built after transportation in the fields. Sheep and goat manure have also a high resistance: In one case, it was not possible to use the penetrometer as the manure was very hard.

With the help of the graphs obtained from the penetrometer we introduced <u>a new characterisation factor</u>: For each graph, we consider the stress at 4 different depths: 35, 45, 55, and 65 cm. We obtain 4 values for each graph and compute the variation coefficient of these values. The heterogeneity coefficient is defined as the mean value of these 4 variation coefficients. By this way, it is possible to obtain a numerical value of heterogeneity. This value is consistant with physical properties inside the heap.

The lowest values were found in compost (9%) and in a 2 years old heap of manure (15%). Low value were also found in wet and soft heaps. Average values are around 30 to 40 %. High values (50 to 60 %) were observed in one heap built by tractor loader, and in another heap under chain cleaner. Major heterogeneities are observed in manure with high stress. This means that the manure has been compacted, but not in an uniform way.




medium heterogeneity
c.v. 40%

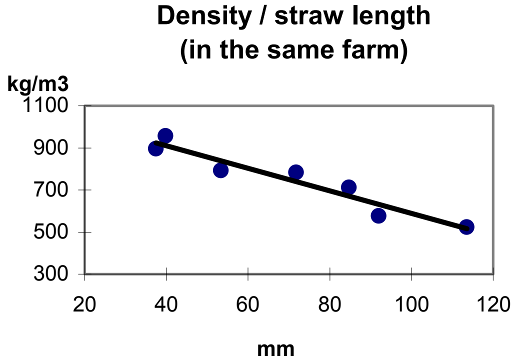
low heterogeneity
c.v.11 %

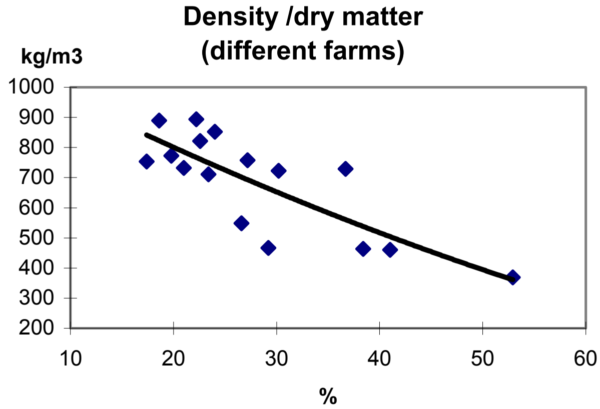
### 3.2 Shear stress

The shear stress appeared to vary from 3 kPa to 50 kPa. One problem appeared with manure with high content of straw. When driving the apparatus into the manure a plug of straw is created. This plug enlarges the hole and the apparatus turns quite freely in this hole. For this reason the measurement is not entirely reliable and it is more advisable not to use this measurement when long pieces of straw are present in the manure.

### 3.3 Bulk density

We observed that the bulk density depends on 2 separate factors. In the same farm, with manure obtained from similar animals, the density depends mainly on the straw length. The dry matter content is quite constant, the length of straw depends on the type of shed, the age of the manure and the location in the shed.
If we compare the sample of manure for a large variety of origins (animals, housing, etc) the range of density is wide and the density mainly depends on dry matter content.




Some other measurements have been made in several regions of France, based on manure density inside the spreader. The point was to help the farmers adjusting the spreader as it should be necessary to know the density in the spreader when adjusting it. High densities (900 kg/m$^3$ to 1000 kg/m$^3$) are found in heaps built by chain cleaner, close to the centre of this heap. Amassed litter bedding in the sheds gives also high density manure especially when stored in the fields in high heaps. Low densities are mainly observed with chicken manure (300 kg/m$^3$)

### 3.4 Straw length

Straw length measurement appeared to be well connected with straw content influence. We have seen how this result is linked to bulk density. We have observed also the variation of this factor during composting operation. The compost was obtained by using a spreader. A first ridge was obtained by operating the spreader in an idle position. This operation was repeated a second time after 15 days.

Original manure 113 mm
After 1 operation 89.7 mm
composted 37 mm

The second length can be explained by the slashing of the straw in the beaters of the spreader.

We observed also in a 2 years old heap of manure that the mean straw length was 39.8 mm in the upper part of the heap but was 53.4mm in the lower part. In the upper part of the heap the manure is aerated and the manure is slowly composted.

### 3.5 Friction coefficient

For most samples of manure the angle of the inclined plane is about 40 degrees when the manure begins to slip. This means that the friction coefficient is f= tan 40 = 0.84

One sticky manure was observed with 1.70 as friction coefficient, but this was an exception. It was not possible to identify classes of manure in order to study the influence of the friction coefficient on power requirement for the conveyor of the spreader.

### 3.6 Dry matter content

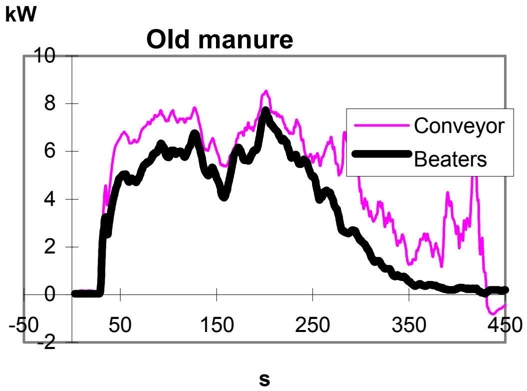
There is a large variety of dry matter content, from 16 % to 53%. High moisture may be due to rainfall. There is usually no protection on manure heaps, but the storage of run-off is compulsory. Sheeps and goats manure is drier than cows manure. Chicken manure of chickens is also dry.

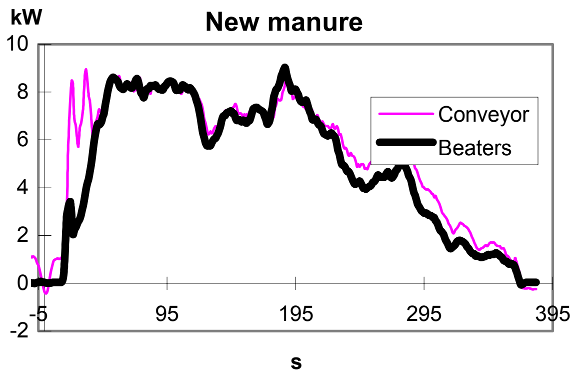
## 4 Influence of manure characteristics on the working of the spreader

**4.1 Bulk density** is the main factor having an influence on the working of the machine. The discharge principle is based on determination of a volume which is spread per unit of time. The Swedish institute has verified that the discharge rate is directly connected to bulk density measured in a characterisation box of 1 $m^3$ volume. In France, it is recommended to weigh the manure in a bucket in order to improve the adjustment of the spreader. As for us we are working on an integrated weighing system incorporated in the manure spreader in order to regulate the discharge rate according to the variation of density.

### 4.2 Shear stress

A new system of discharge regulation is based on torque measurement in the driving of the spreading beaters. We intended to verify whether the torque depends on the discharge rate only, or on the shear stress also. We have measured the torque used for driving the beaters and driving the whole conveyor, with three types of manure: compost, old manure and new manure selected according to the shear stress (10, 16 and 23 kPa). We observed that the power which is necessary to drive the beaters is lower with compost (4,1kW) and old manure (4,8kW) than with new manure (5,7kW). The variation of power on the beaters are directly induced to the power used to drive the conveyor. This means that the beaters push backwards the manure, with a strength depending on the shear stress.



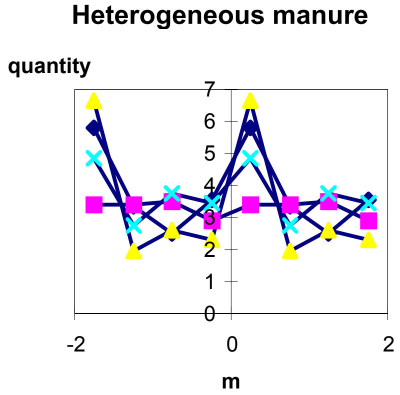



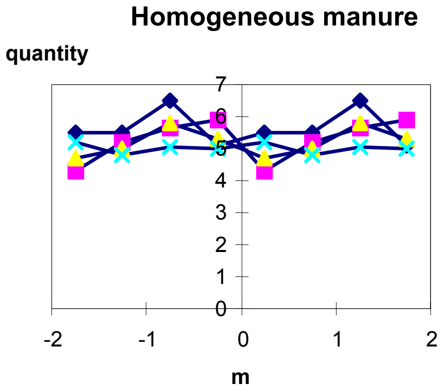

Power used to drive the spreader for old manure and new manure

According to these observations, it is not possible to estimate the discharge rate from the torque value only, when we deal with different types of manure or compost.

### 4.5 Manure heterogeneity

We have used 2 types of manure with the same spreader and the same adjustment. One manure was quite heterogeneous (variation coefficient 49%) the other had a low variation coefficient (9 %) measured with the penetrometer. The variation of quantity spread along a transversal way was measured by the means of trays disposed on the soil. The measurement was repeated 4 times. We obtained a low quality of spreading with the first equipment (29% variation) and a good quality with the second one (8% variation)




This means that it is very important to verify the heterogeneity of manure when we want to test several spreaders or when we need to assess a spreader performance.

## 5. Conclusion

This study has outlined the influence of manure heterogeneity and proposes an easy mean of getting a numerical value of this heterogeneity. A comprehensive test allows to characterise a manure batch and will avoid hazardous conclusions on spreader tests, especially when different manures have been used.

## 6. References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