A model approach for ammonia volatilisation after surface application and subsequent incorporation of manure on arable land.

Une approche par modélisation de la volatilisation de l'ammoniac après épandage en surface ou après incorporation au sol de déjections animales.

J.F.M. Huijsmans and R.M. de Mol
DLO-Institute of Agricultural and Environmental Engineering (IMAG-DLO). Wageningen, The Netherlands
E-mail : J.F.M.Huijsmans@imag.dlo.nl

Abstract

When applying manure to arable land by surface spreading, volatilisation of ammonia takes place. Reduction of ammonia volatilisation can be achieved by incorporation of the manure into the soil. The degree of reduction depends on the method of incorporation and the time-lag between application and incorporation. In general, direct incorporation with a mouldboard plough gives higher reductions than incorporation by a fixed tine cultivator. However, in reality there will always be some time between the spreading and incorporation and during this time volatilisation of the ammonia from the surface-applied manure takes place. The time-lag between application and incorporation depends on the dimensions of the plot, the working width and working speed of the machines and on the work organisation: two-man system, i.e. spreading and incorporation simultaneously, or one-man system, i.e. spreading and incorporation consecutively. To assess the ammonia volatilisation after spreading and incorporation of manure, the time-lag between these two operations was modelled via computer simulation. In a case study the effects on the reduction of volatilisation of the capacities of an incorporator and spreader were shown. Simulation showed that incorporation by a mouldboard plough does not always result in lower ammonia volatilisation than incorporation by a fixed tine cultivator due to differences in capacity. The plot size, work capacity of the spreader, work organisation, incorporation method and capacity, volatilisation rate of surface applied manure, etc. affect the overall ammonia volatilisation. The model showed to be a good instrument to evaluate the effects of different management strategies for manure spreading and incorporation on the ammonia volatilisation when applying and incorporating manure on plot scale.

Résumé

Lorsque les déjections animales sont épandues sur les terres, l'ammoniac se volatilise. La réduction de ce processus de volatilisation ammoniacale peut être obtenue par incorporation des déjections (lisiers) au sol. Le niveau de réduction dépend principalement de la méthode d'incorporation et du délai entre l'épandage et l'incorporation. En général, l'incorporation directe par retournement labour permet de meilleurs taux de réduction que l'incorporation par dents rigides (cultivateur fixe). Cependant, il y a toujours un délai entre l'épandage et l'incorporation et l'ammoniac se volatilise pendant ce délai. Ce délai entre épandage et incorporation dépend de la surface de la parcelle, la largeur de passage de l'épandeur et de la vitesse de travail des équipements et globalemnet de l'organisation du chantier d'épandage : système avec deux opérateurs (soit épandage et incorporation simultanés), ou système avec un opérateur donc épandage et incorporation consécutifs. Afin de vérifier la volatilisation de l'ammoniac ce délai entre les deux opérations a été modélisé. A travers l'étude d'un cas, l'effet sur la réduction de la volatilisation des capacités d'un épandeur et d'un enfouisseur a été établi. Les simulations démontrent que l'incorporation par labour ne s'accompagne pas toujours de pertes en NH_3 inférieures comparativement à l'incorporation par dents rigides, cela notamment à cause de différences de capacités. Le modèle s'avère un outil utile pour évaluer les effets de différents modes de gestion des épandages de déjections et d'incorporation sur la volatilisation de l'ammoniac.

1. Introduction

When applying manure to arable land by surface spreading, volatilisation of ammonia takes place. Reduction of ammonia volatilisation can be achieved by incorporation of the manure into the soil. The degree of reduction depends on the method of incorporation. The manure can be directly injected into the soil or, after surface spreading, be incorporated by different tillage implements.

Huijsmans[1] (1991) compared the ammonia losses after applying slurry with an arable land injector equipped with spring tines with the losses when using the spring tines to incorporate surface applied manure. The injector placed the manure directly underneath the soil surface, at the same time carrying out a tilling operation by burying the manure with soil; the incorporation of the manure by the spring tines resulted in mixing the manure and soil and partly burying the manure with soil. Injection almost completely prevented any ammonia volatilisation.

Different tilling techniques have been investigated in recent years to reduce volatilisation (Van de Molen et al.[2], 1990; Huijsmans[1], 1991; Mulder and Huijsmans[3], 1994; Huijsmans and Hol[4], 1995). It was shown that the degree of volatilisation depends on the method of incorporation. Soil type, soil condition and incorporation technique may determine the volatilisation rate. Burying and intensive mixing of the manure with the soil (increased interaction between soil and manure) resulted in a higher reduction of the volatilisation. Complete burying of the manure by the mouldboard plough gave 90% reduction compared to surface spreading.

Depending on the intensity of mixing of the manure with the soil and the soil condition, other tillage implements achieved a reduction of the volatilisation from 40% to more than 90%. Experiments in which the incorporation was delayed by 3 and 6 hours showed a higher volatilisation compared with direct incorporation [4].

All data on ammonia losses after manure application and incorporation are derived from trials in which incorporation took place directly or at a set time following the spreading on a small scale field plot. However, in reality there will always elapse time between the spreading and incorporation, and this period is not precisely controlled. The ammonia volatilisation rate from surface-applied manure is not linear with time but peaks the first hours after spreading (Figure 1). When manure is spread and incorporated on farm field scale the time between spreading and incorporation thus affects the overall ammonia volatilisation.

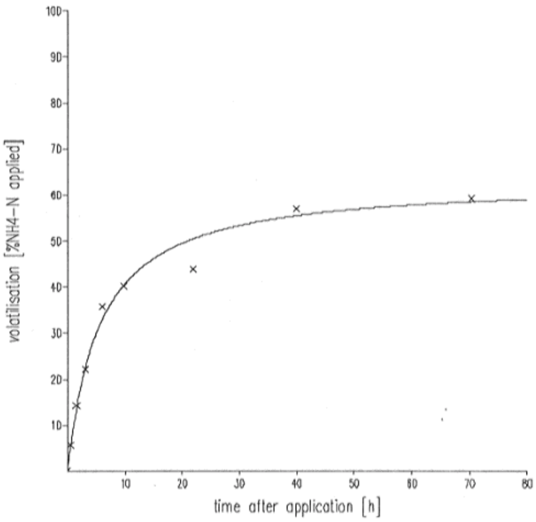

Figure 1
Cumulative ammonia volatilisation after slurry application as a percentage of the ammonium nitrogen applied (after Huijsmans and Hol[4], 1995)

The time to carry out field operations such as manure spreading and a tillage operation depends on the circumstances (such as dimensions of plot, working speed and width of the implements) and the work organisation (Hunt[5], 1986; Witney[6], 1995). To assess the ammonia volatilisation from manure applied and incorporated in two sequential operations, the time-lag between spreading and incorporation needs to be known. Combining this time-lag with a volatilisation curve of surface-applied manure and the potential volatilisation reduction by a particular tillage implement will give the actual volatilisation of a manured field.

In different countries in Europe the reduction of ammonia losses is a big issue to control environmental pollution. One of the policies to reduce ammonia losses is incorporation of surface-applied manure. To investigate the effectiveness of incorporation of surface-applied manure a computer model was developed to simulate the spreading and incorporating operations and to calculate the ammonia volatilisation. In the present study the factors that affect the time-lag between spreading and incorporation are analysed to assess the reduction of ammonia volatilisation of a manured and incorporated plot.

2. Materials and methods

A simulation model was developed to calculate the relation between the time-lag between spreading and incorporation, and ammonia volatilisation for each point of an arable plot. The time-lag depends on the circumstances (dimensions of plot, working speed and width of the machines, distance to manure storage, etc.) and the work organisation: two-man system, i.e. spreading and incorporation simultaneously, or one-man system, i.e. spreading and incorporation consecutively.

In the model the time-lag is calculated by simulation of the activities on the plot. Given the time-lag, the volatilisation is determined by the volatilisation function and the reduction of the volatilisation by the incorporation implement. A combination of the time-lag and the volatilisation gives the average volatilisation and the reduction of the volatilisation for the whole plot. Furthermore, the model gives the average time delay and a division of the time spent over the activities spreading and incorporation.

2.1. Process description

In practice a manure spreader applies the manure on a plot until the whole plot is manured. Each time the spreader is empty it is driven to a manure storage to reload. The manure storage can be nearby at the side of the field or located at some distance. Incorporation can start during or after the manuring of the plot. To calculate the actual time-lag between spreading and incorporation some activities and process parameters need to be defined.

2.1.1. Definitions

A rectangular plot is considered (Figure 2). The operations application and incorporation of manure are performed in **passes** to and fro across the plot. Two successive passes form a **round**. The application equipment is called the **spreader** and the incorporation equipment is called the **incorporator**. Both the spreader and the incorporator have a working speed and a working width. The **capacity** of the incorporator is defined as the working speed times the working width. This is the work capacity neglecting turning and waiting time. The capacity of the spreader is also the work capacity, neglecting turning time, but taking the time for reloading into account. The reloading time is the combination of time required for driving to and from the storage, handling and turning at the manure storage and filling the spreader.

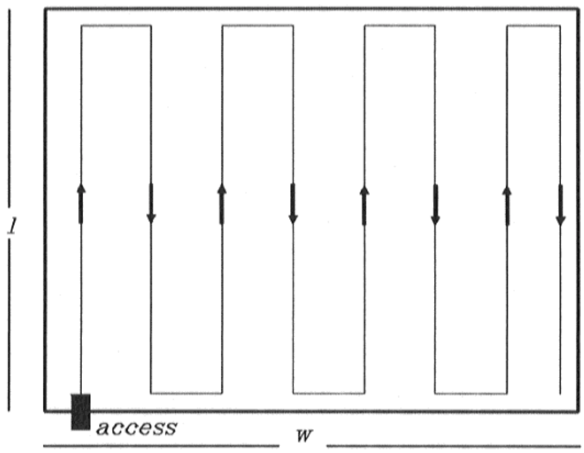

Figure 2
Scheme of a plot (length / and width w) and passes of an implement.

More formally the capacity of the incorporator is defined as:

$$Cap_i = \frac{w_i \cdot v_i}{10} \quad (1)$$

with :
Cap_i capacity of the incorporator [$ha \cdot h^{-1}$]
w_i working width of the incorporator [m]
v_i working speed of the incorporator [$km \cdot h^{-1}$]

The capacity of the spreader is defined by:

$$Cap_s = \frac{1}{\left(\frac{10}{w_s \cdot v_s} + \frac{m_s \cdot r_s}{p_s}\right)} \quad (2)$$

with :
Cap_s capacity of the spreader [$ha \cdot h^{-1}$]
w_s working width of the spreader [m]
v_s working speed of the spreader [$km \cdot h^{-1}$]
m_s manure application rate [$m^3 \cdot ha^{-1}$]
r_s reloading time per tank load [h]
p_s pay load per tank [m^3]

2.1.2. Work organisation

The process of application and incorporation of manure is influenced by many factors. Technical factors are the dimensions of the plot, the working speeds, the working widths, the manure application rate and the pay load of the spreader. Also two main types of work organisation can be distinguished :

1) Working method for manure application
Three working methods are being considered :

– **whole rounds**: a new round (to and fro) is started only if there is enough manure in the tank, otherwise the tank is loaded first;

– **whole passes**: a new pass (there or back) is started only if there is enough manure in the tank, otherwise the tank is loaded first;

– **interrupted passes**: application continues till the tank is empty; after reloading the interrupted pass is continued in the same direction and at the same place where it stopped before loading.

–

2) Working method for manure incorporation
Application and incorporation can be carried out simultaneously (**two-man system**) or consecutively (**one-man system**);

In a **two-man system** one person is available for manure application and another one for incorporation. The spreader and the incorporator can work independently. The spreader is applying manure, alternated with loading of the tank if needed. Loading is done before a new round, before a new pass or when the tank is empty, depending on the chosen working method. The incorporator starts when there is enough manured land available for a whole round or at a later stage after a set waiting time. The incorporator is continuously making whole rounds over the plot. Interruptions can occur when the incorporator catches up with the spreader due to a relative high work capacity of the incorporator or when loading of the spreader takes a lot of time. The incorporator waits till a whole manured round can be incorporated.

In a **one-man system** one person alternates spreading and incorporating; spreader and incorporator are alternately active. The spreader starts with loading of the tank and is working till the tank needs to be reloaded. The spreader drives to the access of the plot, the operator steps over to the incorporator and starts to incorporate the surface-applied manure. After the incorporation the incorporator drives to the access of the plot, the operator steps over on the spreader and continues by loading it. The incorporator makes as many whole rounds as possible, after which a change over to the spreader takes place at the access. This sequence is repeated till manure is applied and incorporated on the whole plot.

2.2. Model description

2.2.1. Volatilisation

The ammonia volatilisation of applied manure can be divided into the volatilisation until incorporation and the volatilisation after incorporation. A volatilisation model was made that calculates the total volatilisation for each point of the plot (before and after incorporation) taking into account the time-lag between the spreader and incorporator at that point of the plot. To achieve this the plot was divided into **strips** (Figure 3). The volatilisation was first calculated per strip and later averaged over all the strips to assess the total emission of the plot. The length of a strip equalled the length of the plot; the strip width was taken as the greatest common divisor of the working widths and the plot width. Both the spreader and the incorporator operated on an integer number of strips in each pass.

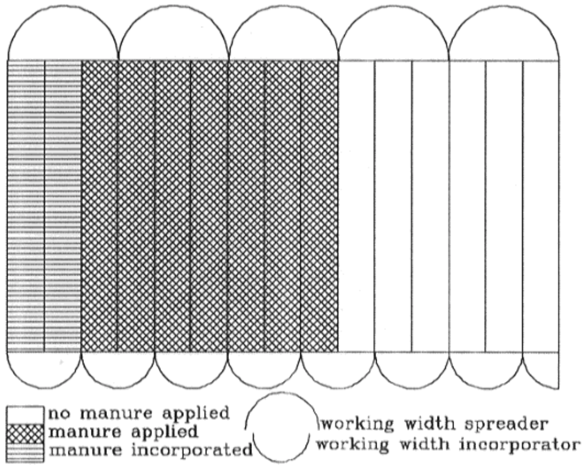

Figure 3
Example of a situation during simulation on a plot divided into 15 strips, where manure has been applied on nine strips and where two strips have been incorporated.

The model for the volatilisation until incorporation is based on experiments in which the volatilisation was determined as a function of the time after application (Figure 1). A non-linear volatilisation function can be fitted for this curve :

$$Vol(\Delta t) = \frac{\Delta t}{\beta_0 + \beta_1 \cdot \Delta t} \quad (3)$$

with :

Δt	time-lag between application and incorporation [h]
$Vol(\Delta t)$	Ammonia volatilisation for time-lag Δt [% of total NH_4-N applied]
$ß_0$ and $ß_1$	Parameters of the volatilisation function [$h \cdot \%^{-1}$], [$\%^{-1}$]

The parameters $ß_0$ and $ß_1$ are fitted by using the results of experiments in which the volatilisation of non-incorporated manure is measured.

The time-lag Δt depends on the operating direction of the spreader and incorporator :

– if the incorporator operates in the same direction on a strip as the spreader, then:

$$\Delta t(x) = \left(t_{0i} + \frac{x}{v_i} \right) - \left(t_{0s} + \frac{x}{v_s} \right) \quad (4a)$$

– if the incorporator operates in a direction on a strip opposite to the spreader, then:

$$\Delta t(x) = \left(t_{0i} + \frac{x}{v_i} \right) - \left(t_{0s} + \frac{l - x}{v_s} \right) \quad (4b)$$

with:

x	location on the strip, $0 \le x \le l$ [km]
$\Delta t(x)$	time-lag at point x [h]
t_{0i}	time the incorporator started with the strip [h]
t_{0s}	time the spreader started with the strip (equals 0 for the start of the simulation) [h]
l	length of a strip (equals the length of the plot) [km]

The average volatilisation until incorporation for a strip j is :

$$Vol_{u,j} = \frac{1}{l} \int_{x=0}^{x=l} Vol(\Delta t(x))dx = \frac{v_i}{l} \int_{t=0}^{t=t_l} Vol(\Delta t(v_i \cdot t))dt \quad (5)$$

with :

$Vol_{u,j}$	average volatilisation until incorporation for strip j [% of total NH_4-N applied]
t_l	time needed by the incorporator to incorporate a whole strip [h]

The transformation $x = v_i \cdot t$ is applied to transform the place-dependent integral to a time-dependent integral that can be used in the simulation model.

The average volatilisation after incorporation for a strip j is :

$$Vol_{a,j} = \frac{100 - PotRed_i}{100} \cdot (Vol(\infty) - Vol_{u,j}) \quad (6)$$

with :

$Vol_{a,j}$	volatilisation after incorporation for strip j [% of total NH_4-N applied]
$PotRed_i$	potential volatilisation reduction of the incorporator [%]
$Vol(\infty)$	total ammonia volatilisation of surface-applied manure after Eqn (3) [% of total NH_4-N applied]

The volatilisation after incorporation at varying time-lags after spreading is generally not known. In experiments the volatilisation after incorporation was measured in trials in which manure was incorporated directly or at a set time following spreading on a small scale field plot [1,2,3,4]. The measured volatilisation reduction when direct incorporating is used in the model as the potential reduction in volatilisation of the incorporator $PotRed_i$. This potential reduction is assumed to be constant for each incorporation method independent of the time-lag between spreading and incorporation. For example, if incorporation with a plough gives a reduction of 90% in case of direct incorporation (potential volatilisation reduction), then this percentage of reduction is also assumed for the remaining volatilisation after a certain time-lag. This means that 10% of the ammonia that would have volatilised from that moment, in case of no incorporation, is volatilised when incorporating at that moment.

The average total volatilisation for strip j is the sum of the volatilisation until incorporation and the volatilisation after incorporation :

$$Vol_j = Vol_{u,j} + Vol_{a,j} \tag{7}$$

with:

- Vol_j volatilisation until and after incorporation for strip j [% of total NH_4-N applied]

The average total volatilisation of the whole plot is the average over all strips :

$$Vol = \frac{1}{N}\sum_{j=1}^{N} Vol_j \tag{8}$$

with :

- Vol average volatilisation for the whole plot [% of total NH_4-N applied]
- N number of strips

2.2.2. Process simulation

To determine the time-lag between the spreader and the incorporator the process of application and incorporation of manure was simulated by the simulation model CAESAR (Computer simulation of the Ammonia Emission of Slurry application and incorporation on ARable land). The model works with the simulation software package PROSIM (Prosim[7], 1994). PROSIM makes it possible to simulate discrete and continuous processes simultaneously. Spreading and incorporating are continuous processes interrupted at discrete moments for turning, reloading or waiting. The processes are simulated according to the description in section 2.1.

In a two-man system, the spreader is continuously making passes on the plot and reloading the tank, till the whole plot is manured. In this case the activities of the incorporator may depend on the activities of the spreader; the incorporator can only start a new round if enough manured land is available to make a whole round. In a one-man system, the spreader and the incorporator are alternately active.

Input for the simulation model exists of parameters of volatilisation, spreader and incorporator as well as general parameters.

General parameters :

– one-man or two-man system
– whole round, whole passes or interrupted passes
– length of plot l [km]
– width of plot [km]
– strip width [m]
– manure application rate m_s [$m^3 \cdot ha^{-1}$]
– idle travel speed on the field of the spreader and incorporator [$km \cdot h^{-1}$]

– waiting time for the incorporator in a two-man system
– changing time from spreader to incorporator or reverse in a one-man system [min]

Volatilisation parameters :
Characteristics of the volatilisation function, i.e. parameters in Eqn (3)

Spreader parameters :
– working speed v_s [km·h^{-1}]
– working width w_s [m]
– pay load p_s [m^3]
– time to turn [sec]
– travel speed on the road [km·h^{-1}]
– distance to manure storage [km]
– time for handling and turning before and after reloading [min]
– loading capacity [m^3·min^{-1}]

Incorporator parameters:
– working speed v_i [km·h^{-1}]
– working width w_i [m]
– time to turn [sec]
– potential volatilisation reduction of the incorporator $PotRed_i$, as defined in Section 2.2.1 [%]

The simulation starts with the spreader (with loaded tank) and incorporator ready at the access to the plot. The access to the plot is located in the corner of the plot (Figure 2). In the model the spreader can be busy with different activities: working, waiting, driving on the plot, reloading, turning. The incorporator may be working, waiting, driving on the plot or turning. In the one-man system also changing from spreader to incorporator or reverse takes place. Figure 3 shows a possible situation during a simulation run.

The main results generated by the simulation model are :
– average time-lag between application and incorporation;
– average volatilisation until incorporation;
– average total volatilisation (before and after incorporation);
– average reduction in volatilisation (compared with no incorporation at all);
– total time needed for application and incorporation;
– division of the total time over the different activities of the spreader and the incorporator.

3. Simulations

With the model many different situations can be simulated and the results are used to calculate the total volatilisation from a manured and incorporated plot and time needed for application and incorporation. From the model description it is expected that the capacity of the spreader (Cap_s) and the incorporator (Cap_i) as defined in Eqn (1) and (2), will have a major effect on the reduction of the volatilisation. The volatilisation when spreading and incorporating in two gangs can approach the volatilisation of direct incorporation when the difference between the capacities of the spreader and the incorporator is minimised: the potential volatilisation reduction of the incorporator is approached. In the following case this hypothesis is tested by studying the relation between the capacity of the incorporator (Cap_i) and the spreader (Cap_s) and the resulting reduction of the volatilisation compared with no incorporation, taking into account different potential volatilisation reduction rates of the incorporator.

3.1. Input parameters

The plot size is taken 4.8 ha (length 0.2 km and width 0.24 km) and the strip width is 0.5 m. After each pass along the plot both the spreader and the incorporator turn; the time to turn is 20 and 30 s respectively. The travel speed of the spreader and incorporator on the field, while not in operation, is 10 $km \cdot h^{-1}$. The two-man system and whole rounds are assumed. At the beginning the incorporator starts 3 min later than the spreader if there is enough manured land available for a whole round. The manure storage is placed at the edge of the field near the access; eliminating road transport to a manure storage. The loading capacity of the spreader is 3 $m^3 \cdot min^{-1}$, handling and turning before and after the loading of each load takes altogether 2 min.

The potential volatilisation when the manure is not incorporated is based on the volatilisation as shown in Figure 1. Fitting Eqn (3) results in the parameter values: $ß_0$ = 0.087 and $ß_1$ = 0.016 (accounts for 98.5% of the variance). The maximum volatilisation, when not incorporating, is 60% of the total ammonia applied.

To study the effect of the relation between the capacity of the incorporator (Cap_i) and the spreader (Cap_s) on the reduction of the volatilisation, taking into account different potential volatilisation reduction rates of the incorporator, a selection is made of a range of practical possibilities in Dutch circumstances. For the spreader the following situations were considered :

- working speed v_s: 6, 8 or 10 $km \cdot h^{-1}$ (n = 3);
- working width w_s: 8, 10 or 12 m (n = 3);
- pay load p_s varying from 6 to 22 m^3, with steps of 2 m^3 (n = 9);
- manure application rate m_s: 10, 15, 20, 25, 30, 35, 40, 50 and 60 $m^3 \cdot ha^{-1}$ (n = 9).

These situations yield 729 (3×3×9×9) possible combinations for the spreader. Tuning the pay load of the spreader with the manure applied for an integer number of rounds (practice) eliminates unpractical combinations resulting in 189 remaining combinations. For 18 combinations with a high application rate the working method with whole rounds was impossible, the method with whole passes was used instead.

For the incorporator the following situations were considered:

- working speed v_i varying form 2 to 10 km·h^{-1}, with steps of 2 km·h^{-1} (n = 5);
- working width w_i: 1, 1.5, 2, 2.5, 3, 4, 5 and 6 m (n = 8);
- potential volatilisation reduction $PotRed_i$ varying from 40 to 90%, with steps of 10% (n = 6).

These situations yield 240 (5×8×8) possible combinations for the incorporator. The working speed of the incorporator was chosen in a range in which most tillage implements may work in suitable soil conditions. The working widths were chosen in the way that the smaller working widths were more common for a plough and the larger ones for a cultivator. The potential volatilisation reductions of the incorporator corresponded with different kinds of measured reductions [1,2,3,4].

The total number of combinations for the spreader and the incorporator is 45360 (189 × 240). For the simulations a random selection of 10 spreader combinations was made (Table 1). Each of these combinations was combined with all 240 incorporator combinations to analyse the volatilisation reduction when applying and incorporating manure on a whole plot.

3.2. Simulation results

The resulting spreader capacity of the 10 randomly selected spreader combinations is given in Table 1. For spreader combination 1 (capacity 2.93 ha·h^{-1}) the relation between reduction of the volatilisation and the capacities of the incorporator is shown for the different potential volatilisation reduction in Figure 4.

number	working speed v_s [km·h^{-1}]	working width w_s [m]	application rate m_s [m^3]	pay load p_s [m^3]	reloading time r_s [h]	capacity [ha·h^{-1}]
1	6	8	15	10	0.09	2.93
2	6	15	10	6	0.07	4.50
3	8	10	25	20	0.14	3.27
4*	8	15	40	12	0.10	2.40
5	10	8	15	10	0.09	3.87
6	10	8	60	20	0.14	1.79
7	10	12	15	22	0.16	5.28
8	10	12	20	20	0.14	4.39
9	10	15	25	16	0.12	3.88
10*	10	15	60	18	0.13	1.96

* spreader combination where whole rounds are not possible

Table 1
Parameter values for the 10 randomly selected spreader combinations and their capacity

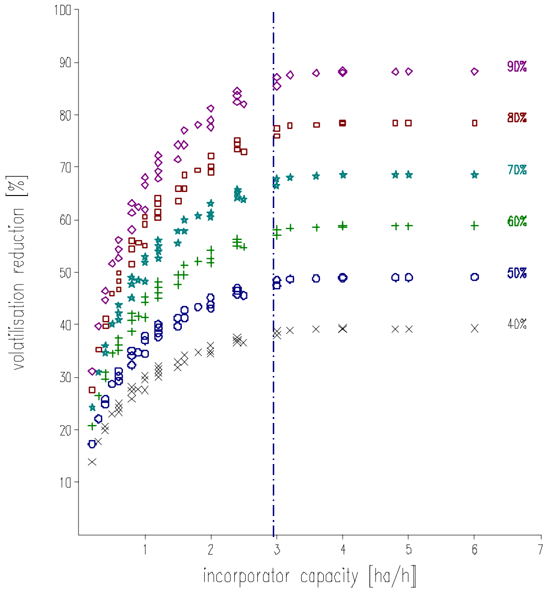

Figure 4
Volatilisation reduction as a function of the capacity of the incorporator for the first spreader combination; for six levels of potential volatilisation reduction of the incorporator (the vertical line shows the capacity of the spreader).

As the incorporator capacity increased, the reduction approached the maximum level of reduction, which corresponded with the potential reduction of the incorporator at direct incorporation. This maximum volatilisation reduction was reached when the capacity of the incorporator was at least as high as the capacity of the spreader. The vertical line in Figure 4 shows the capacity of the spreader. Increasing the capacity of the incorporator after this point will not increase the reduction of volatilisation. The reduction was lower when the capacity of the incorporator was lower; at this stage there was a non-linear relationship between the capacity of the incorporator and the reduction of volatilisation.

Characteristics of Figure 4 proved to be also apparent for the other nine spreader combinations mentioned in Table 1. This finding means that it may be possible to estimate the reduction of volatilisation for this plot size given only the capacities of the spreader and the incorporator. However, the point where the maximum level of reduction can be approached will be determined by the point where the capacity of the incorporator equals the capacity of the spreader.

4. Discussion

Some incorporators as defined in section 3.1 have the same capacity, e.g. a capacity of 1.2 $ha \cdot h^{-1}$, when the working width is 2 m and the working speed is 6 $km \cdot h^{-1}$ (case 1), but also when the working width is 3 m and the working speed is 4 $km \cdot h^{-1}$ (case 2). The related volatilisation reduction differs, as can be seen in Figure 4, but this difference is relatively small. For example, in case of 70% potential reduction of the incorporator the reduction of volatilisation is 53.9% (case 1) and 55.1% (case 2). For incorporators with the same capacity, the highest volatilisation reduction is reached for the incorporator with the greatest working width, which can be explained by smaller total turning time.

The potential volatilisation reduction of an incorporator can never be reached, because the time-lag between spreader and incorporator never equals zero. In the simulation model it is assumed that the incorporator starts with a new round only when enough manured strips are available for a whole round; during this waiting time volatilisation takes place.

In the case study the effect of the capacity of the incorporator on the reduction of volatilisation was presented for a given set of capacities of the spreader. Changes in the capacity of the spreader will directly show at which stage a maximum reduction of volatilisation can be reached by the incorporator, as is show in Figure 3 by the vertical line. The capacity of the spreader depends on different aspects. The manure application rate and the pay load of the tank determine the number of refillings of the tank for a certain plot. The total refilling time depends on the distance to the storage, loading time and travel speed. The working width, working speed and turning times on the plot determine the time for the actual spreading. Changes in these parameters will effect the spreader capacity and so at which the stage a maximum reduction of volatilisation can be reached by an incorporator.

The reduction of volatilisation for two potential reductions of volatilisation of the incorporator is shown for varying capacities of the incorporator in Figure 5. This figure is suitable to analyse the reduction of volatilisation when choosing different kinds of tillage implements to incorporate the manured plot, given the potential volatilisation reduction of the incorporator and its incorporation capacity. For example, a mouldboard plough will give a potential volatilisation reduction of 90% and a spring tine cultivator 50%. Taking spreader combination 1 from Table 1, the volatilisation reduction can be calculated (Figure 5). The plough may have a working speed of 3 $km \cdot h^{-1}$ and a working width of 1.5 m (capacity 0.45 $ha \cdot h^{-1}$); the spring tine 8 $km \cdot h^{-1}$ and 6 m, respectively (capacity 4.8 $ha \cdot h^{-1}$). From Figure 5 it can be read that the mouldboard plough results in a reduction of 46% and the spring tine cultivator in 49%. This example shows that though the potential reduction of the plough is higher than the potential reduction of the spring tine cultivator, the overall volatilisation reduction of the plough is lower when incorporating a whole manured plot. A higher capacity of the plough (more than 0.5 $ha \cdot h^{-1}$) will result in a higher volatilisation reduction than with the spring tine cultivator. In the same way the capacity of the spring tine cultivator may be lowered to 2.2 $ha \cdot h^{-1}$ to reduce the volatilisation to the same level as the plough.

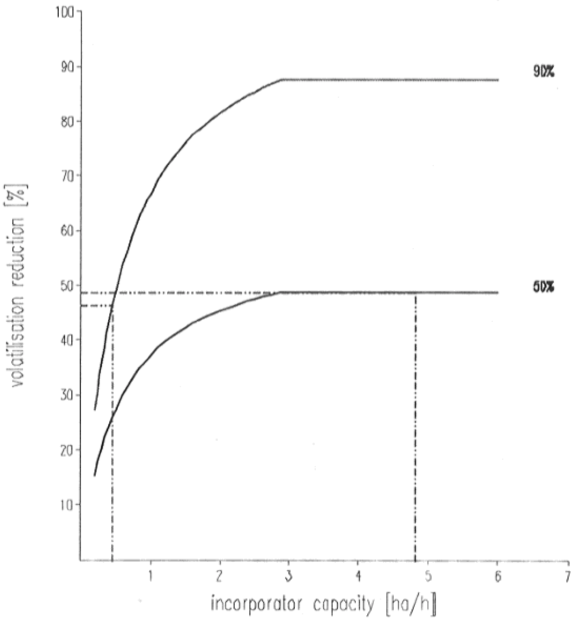

Figure 5
Volatilisation reduction as a function of the capacity of the incorporator for the first spreader combination ; for a potential volatilisation reduction og 90% (plough) and 50% (spring tine cultivator).

In the case study some features and possibilities of the model are described. Other parameter settings will result in other outcomes. For example, changing the plot size and/or the volatilisation function directly influences the outcome. However, the maximum volatilisation reduction is reached when the capacity of the incorporator is at least as high as the capacity of the spreader. The model makes it possible to study the volatilisation after incorporation for different situations. The model also gives the average time-lag and a division of the spent time over the activities for the spreading and incorporation implement. A next step in the research will be to optimise the process of spreading and incorporations in terms of ammonia losses versus costs.

5. Conclusion

Volatilisation and reduction of volatilisation after surface application and subsequent incorporation of manure on arable land was affected by the time-lag between spreading and incorporation. The CAESAR model enables the calculation of the time differences, between spreading and incorporation, and ammonia volatilisation for each point of an arable plot. The time-lag depended on the circumstances (such as dimensions of plot, working speed and width) and the work organisation.

The case study showed that incorporation by a plough not always results in lower ammonia volatilisation than incorporation by a spring tine cultivator in spite of the potential higher reduction of volatilisation by the plough. The input parameters plot size, work capacity of the spreader and the incorporation method, volatilisation rate of surface applied manure, etc. affected the overall ammonia volatilisation.

The model showed to be a good instrument to evaluate the effects of different manure spreading and incorporating management strategies on the ammonia volatilisation when applying and incorporating manure on plot scale.

6. References

1. **Huijsmans, J.F.M**. Possibilities for slurry application before and after drilling sugar beet. Proceedings 54th Winter Congress, Institut International de Recherches Betteravieres, Brussel, p. 109-124, 1991.

2. **Molen, J. van de, Faassen, H.G. van, Leclerc, M.Y., Vriesema, R. and Chardon**, W. Ammonia volatilisation from arable land after application of cattle slurry.1. Field estimates. Neth. Journal of Agricultural Science, 38/2, 145-158, 1990.

3. **Mulder, E.M. and J.F.M. Huijsmans**. Beperking ammoniakemissie bij mesttoediening. Overzicht metingen DLO-veldmeetploeg 1990-1993. DLO, Wageningen 71 pp, 1994.

4. **Huijsmans, J.F.M. and J.M.G. Hol**. Ammoniakemissie bij het in een tweede werkgang onderwerken van dunne varkensmest op bouwland. IMAG-DLO rapport 95-13, Wageningen, 32 pp, 1995.

5. **Hunt, D.R**., 1986. Engineering models for agricultural Production. The Avi Publishing Company, Westport, Connecticut, 260 pp.

6. **Witney, B.D.,** 1995. Choosing & using farm machines. Land Technology Ltd., Edinburgh, 412 pp.

7. **Prosim**, 1994. Prosim User Guide, Sierenberg & de Gans bv, Waddinxveen, The Netherlands, 134 pp.