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Report 1569

Towards general guidelines for the management of bioslurry in Kenya

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Title **Towards general guidelines for the management of bioslurry in Kenya**

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Contents

Summary and recommendations

The project "Optimal use of bioslurry as a fertilizer" is being performed by Nutrient Management Institute NMI in order of Hivos Foundation in the period from November 2014 to July 2015. Within the scope of this project a practical user manual for the optimal use of bioslurry in Kenya is elaborated.

From this study it has become clear that nitrogen can get lost from bioslurry during the following steps:

- anaerobic digestion, which may lead to relatively low nitrogen (N) losses by ammonia (NH_3) volatilization;
- handling, such as separation of slurry into a solid and liquid fraction, drying and/or composting of (the solid fraction of) bioslurry and/or disposal of the liquid fraction.
- storage, which may lead to high nutrient losses by overflow of bio-slurry, if the capacity of the storage is not large enough. Moreover, N losses may take place by NH_3 volatilization (up to 70% of total N), which may be esp. high if the storage is not covered.
- application: directly after the application of bioslurry, the risk for N losses by NH_3 volatilization is high and may be up to 50% of the total amount of NH_4-N in the slurry. The largest part of the NH_3 volatilization takes place within the first 24 hours after application.

Measures should be taken to prevent those losses. Those measures will be an important element of the user manual.

Basic guidelines for a user manual for bioslurry consist of the following elements:

1. guidelines for the reduction of nutrient losses during the bioslurry production chain, i.e. during the anaerobic digestion, storage, handling and during and after application.
    - Take measures to reduce nutrient losses during bio-slurry storage:
        - The storage capacity should be sufficient to prevent overflow;
        - N losses from bio-slurry by NH_3 volatilization should be minimized by closing or covering the storage;
        - Leaching of (nutrients from) bio-slurry should be preferably prevented by an impermeable barrier at the bottom of the storage.
    - Take measures to reduce nutrient losses during bio-slurry handling (drying, composting, etc.):
        - During the handling stage, it is of importance that all fractions of bioslurry are collected and no part (e.g. the liquid fraction) is disposed.
        - Drying of untreated bioslurry or the solid fraction of bioslurry should be avoided.
        - If bioslurry is composted, the bioslurry should be composted together with materials with high C/N-ratio (e.g. straw and/or woody material, such as prunings) to prevent N losses by NH_3 volatilization.
    - Take measures to reduce nutrient losses during and after bio-slurry application:
        - If the consistency of the slurry is rather solid, dilute the slurry till it is rather fluid;
        - Try to inject the slurry into the soil or cultivate the soil after application of the bioslurry;
        - Apply the slurry during a period with little wind and low temperatures (e.g. in the morning or evening).

2. guidelines for the optimum application (optimum amount, way and time of application), which consist of:
    - The determination of the nutrient requirement in a specific situation, characterized by the combination of crop, soil, region and season. For that reason it is advised to make use of

fertilizer recommendations based on soil samples.
- The composition (nutrient content, dry matter, organic matter, pH) of the bioslurry. The following options are available for a determination: i) standard laboratory analysis, ii) estimation of the composition with quick tests and/or iii) by spectroscopy.
- The optimum amount of bioslurry application could be derived from the former steps. An outcome of this evaluation could be that mineral fertilizers are required in addition.
- With respect to the place of bioslurry application we recommend to apply it within the vicinity of the plant roots, in such a way that it is does not lead to salt stress and that it does not lead to nitrogen losses (see guidelines formulated above).
- With respect to the timing of the bioslurry application, it is important that the nutrient supply from the bioslurry should be synchronized with the nutrient requirement of the crop. This means for example that the bioslurry should not be applied in a period without crop growth with high amounts of rainfall (because of leaching losses).

Our recommendations for future activities are as follows:
- Discussion with local partners about the guidelines that have been formulated in this study;
- Evaluation of the possibilities and eventual objections which are associated with the implementation of the optimized guidelines in practice;
- Further development of the second part of the guidelines, i.e. the determination of the optimum amount of bioslurry application, based on soil and bioslurry analyses, in close cooperation with a regional laboratory working on fertilizer recommendations (www.soilcares.com);
- Implementation of guidelines in existing programmes for the dissemination of bioslurry knowledge to farmers (e.g. of ABPP, KENDBIP for Kenya and/or TDBP for Tanzania).

1 Introduction

1.1 Background and objectives

The project "Optimal use of bioslurry as a fertilizer" is being performed by Nutrient Management Institute NMI in order of Hivos Foundation in the period from November 2014 to July 2015. Within the scope of this project a practical user manual for the optimal use of bioslurry in Kenya is elaborated.
Problems that are associated with the use of bioslurry and which may lead to suboptimal use are:

- the risk for high losses (especially of nitrogen) during biogas production, storage and application of bioslurry to the field;
- the highly variable and unknown composition of bioslurry, by which it is difficult to apply the optimum dose, and which may lead to over or under application of bioslurry to crops and soils in various situations.

The aim of the project was to develop a general user manual for the optimal use of bioslurry as a fertilizer in varying situations, which may be characterized by

- the type of manure that is used as a feedstock in the biogas digesters,
- the way the digestion process is managed,
- the region, soil type, soil fertility and crop to which the bioslurry is applied.

The idea is that the potential problems that are associated with the use of bioslurry may be overcome by a proper management of the bioslurry production, storage and application. Guidelines for the intended proper management will be the basis for the user manual. The focus for the user manual is on the optimal use of bioslurry in Kenya.
Because several other initiatives on this topic are going on in Kenya, Hivos has proposed to start with the description of the foreseen activities and of a plan about the collaboration with the following organizations and initiatives:

- Kenya National Domestic Biogas Implementation Programme (KENBIP);
- Africa Biogas Partnership Programme (ABPP);
- Waste to Worth project, that is performed by Wageningen University (the Netherlands), Egerton University (Kenya) and SNV Netherlands Development Organisation.

1.2 Waste to Worth project

Within the Global Agenda of Action in support of sustainable livestock sector development, the Netherlands is involved in the Waste to Worth-theme, by the active involvement of the Ministry of Economic Affairs and Wageningen UR (Livestock Research). The group that is working on Waste to Worth-theme has launched the Manure Management Improvement Program (MMIP), which initiates pilots to enhance application of better manure management practices. One of the pilots is planned in Kenya. Optimizing the manure and bioslurry management is expected to play an important role in the availability of forage to dairy cattle in Kenya.
For that reason the project "Enhancing the sustainability of small and medium scale dairy farming systems in Kenya through nutrient cycling and feeding management" has been developed. This project is performed within the scope of the Manure Management Improvement Program (MMIP) and it is a cooperation between Wageningen University (the Netherlands), Egerton University (Kenya) and SNV

Netherlands Development Organisation. The timeline of the project is four years (2014 – 2017) and two PhD students will do an important part of the work. The overall goal of the project is to improve productivity and resilience of the small and medium scale dairy farming systems in Kenya by improving the nutrient and feed resource utilization.

The objectives of the research part of the project are:

- To improve insight in the best practices of integral manure (waste) management strategies at the level of small and medium scale farms, with regard to improved productivity, effects on feed availability and quality, nutrient management (including synthetic fertilizers), soil quality, feasibility of labour and financial investments and acceptance;
- To identify barriers (technical, socio-economic and institutional) to adoption of promising interventions and to develop strategies to overcome these barriers;
- To actively link with the Kenya Market-led Dairy Program (KMDP), disseminate and demonstrate the insights of above mentioned research questions on manure management, soil quality and productivity.

The approach will be a combination of research, demonstration and development involving different stakeholders: knowledge institutions, development organisations and private sector parties (dairy coops and farmers).

The project will start with a literature review on available knowledge about handling bioslurry and manure management techniques for small and medium scale farms.

Parallel to the literature review a baseline study will be conducted to assess the current situation at the farm regarding the manure management, the level of farmers' knowledge regarding manure and feeding management and their attitude.

One of the PhD studies aims at identifying integral manure and slurry management strategies. This will be done by the development of customized manure storage facilities and application methods, including transport and housing, by on-farm research and development and in cooperation with a group of pilot farmers. Moreover, research on experimental sites that is performed within the scope of this PhD study should generate improved insight in:

- effects of different types of manure storage / treatment on losses during storage and application and on crop yield and
- the optimal manure application rates for a number of selected important crops in smallholder mixed farms.

It may be concluded that part of the Waste to Worth project has the same objectives as the Bioslurry project, which is described in this report. To prevent repeating the same activities, it is important to gear the activities to one another in such a way that they are complementary. Especially, the outcomes of the literature review and the baseline study will be of value for the Bioslurry project. Because those activities were planned in the first part of 2014, it was expected that the outcomes would have been available at the start of this project. Moreover, the activities of the PhD studies are relevant for the Bioslurry project. So, it has been tried to get insight into the latest versions of the working plans of the PhD studies and eventual outcomes that has come available until now.

2 Description of activities

The following activities are performed within the scope of the Bioslurry project described in this report:

1. Tuning of the activities to the Waste to Worth project
   Responsible persons from SNV, Wageningen UR and/or Egerton University, who are involved in the Waste to Worth project, are contacted by email and/or phone and asked to supply information about activities and available results from the Waste to Worth project. Based on that information, the foreseen activities are adjusted in such a way that they are complementary and repeating of the same activities is prevented. Moreover, the possibilities to collaborate and to combine activities have been explored. If possible, appointments were made.

2. Developing general guidelines for user manual, which consists of a background document and basic guidelines for user manual (desk study). In the background document, the following elements are described:
   - How can nutrient losses during production, storage and application of bioslurry be prevented? It is explored at which moments and under which conditions the risks for nutrient losses are high and how those losses can be prevented or minimized by practical measures;
   - How can the composition of bioslurry be determined or estimated? Because the composition of bioslurry may be very variable, it is of importance to know that composition for its' optimal use. Various options to determine that composition (by estimation or measurement) will be explored. The possibilities and accuracy of the various options will be investigated, described and translated into practical guidelines.
   - Make an estimation of the amount of nutrients that is required by specified crop-soil combinations. This can be done at the basis of available fertilizer recommendations, which take into account nutrient requirement of crops in dependence of soil type and soil fertility, climate, etc.
   - Determine the optimal application dose of bioslurry based on its' composition and the nutrient requirement of the crops.

3. Developing elaborate user manual for regions in Kenya, consisting of the following activities (desk study; evt combined with field trip and meeting(s)):
   - Contact KENBIP, ABPP and Waste to Worth project and explore collaboration.
   - Selection of the region(s) in Kenya which is considered (in collaboration; criteria: e.g. presence of sufficient small scale biogas digesters, presence Soil Cares, etc.);
   - Inventory of the current practice(s) during biogas production (of which bioslurry is the remaining product), storage and application of bioslurry;
   - Guidelines are given for the adjustment of the current practices, by which nutrient losses may be minimized;
   - It is indicated which method is most suitable for the determination of the composition of bioslurry. The local situation (including available laboratories, costs, etc.) and infrastructure is taken into account
   - Inventory of the most important crops, soil types and soil fertility classes and its' required nutrient application in the selected regions.
   - Evaluation of the current use of bioslurry in selected regions in Kenya. It is described to what extent nutrient losses will take place, which improvements might be possible and which

efficiency increase might be expected. It is indicated to which crops the bioslurry can be applied the best, what is the required dose and what is the optimal time and way of application. Finally, that is translated in practical guidelines.

4. Short final report summarizing implemented activities and outlook towards next phases, including possible collaboration with Waste to Worth project.

3 Current situation with respect to bioslurry management in Kenya

Within the scope of the Waste to Worth project, a case study has been performed with the objectives i) to characterize the current manure management practices on smallholder farms in Kenya, ii) to characterize several aspects of livestock production systems and iii) to determine barriers affecting improvements of manure management practices (Nyaanga et al., 2015).

For that reason a survey was performed on 120 farms in the high potential areas of four counties (Kiambu, Uasin Gishu, Meru and Kisii) in November 2014. The counties are characterized by high population densities and a large number of smallholder farmers. The demand for food is high and soils are subject to continuous and intensive cultivation. Soil fertility tends to decrease in a number of areas, which is a serious threat to food security.

Livestock farming is widespread in the areas, where about 85% of the households are keeping dairy cattle. The manure that is produced by the cattle is of high value, because of its' value as an organic fertilizer and because the costs of artificial fertilizers are often too high for the smallholders.
The main income from the farms was generated by dairy farming (78%) and the residual (20%) by crop farming. The main crop for crop farming was maize.
Several findings from the survey of the manure management:

- The collection of manure was relatively simple (from stables) – because of zero grazing;
- 37% of the farmers used water to flush barns;
- 39% used bedding materials which is removed while mixed with animal excretions;
- 57% had anaerobic digesters, with an average volume of 8,5 m^3, which were mainly filled with urine, dung and flush water;
- None of the farmers stored urine and dung separately;
- 44% of the farmers stored liquid manure in a lagoon without cover or floor; 72% indicated that the storage capacity was sufficient to prevent overflow; in situations where it was not, the overflow was caused by rain water;
- None of the respondents had a toilet connected to the liquid manure storage;
- 35% of the farmers who store liquid manure treated it to become solid and stackable – they dried more than 50% of the liquid manure produced;
- Most farmers (57%) stored solid manure via a pile heap without floor or roof; most of them actively dried solid manure; the reasons for actively drying were to ease storage, transportation and application and to improve quality;
- Slurry was often dried, stored subsequently and applied to the fields; Most of the farms who did not dry the slurry, channeled it directly to the field.

Our impression based on the case study is that several improvements considering the current situation with respect to the manure and bioslurry management in Kenya will be possible. Some possible improvements are as follows:

- In some situations, the storage capacity was too low, which resulted in an overflow of manure / slurry (Figure 3.1). Farmers indicated that this is mainly caused by rainfall. In the optimal situation, all bioslurry can be stored until it is required for crop growth;
- Dung and urine are both used as an input for the digester, while only dung is needed for the digestion process. Separate collection and storage of dung and urine might be interesting, because the dung may be used as input to the digester, while the urine may be directly used as fertiliser.

- In some situations, the bioslurry is dried to ease storage, transport and application. That may lead to high N losses due to ammonia volatilization. So, drying should preferably be prevented.

Moreover, we have the following questions:

- It is unclear how bioslurry is applied to crops and soils. Our questions are:
    - to which crops is bioslurry applied?
    - what is the amount of bioslurry application?
    - how is bioslurry spread over the farm / field? Is it distributed evenly over the crops/plots?
    - how are N losses by ammonia volatilization after bioslurry application prevented? Is it injected into the soil? Or is it infiltrating into the soil rapidly because of its' liquid status?
- We did not find information about the composition of bioslurry. It is not clear if that is available, but from a bioslurry officer of the Tanzania Domestic Biogas Programme, we know that the composition is generally unknown in Tanzania. If information about the composition of bioslurry is not known, it is difficult to determine the optimum application rate. `

The information about the manure management at the smallholder farms that result from the case study will probably be used for the development of plans for future activities. At this moment, we don't know where the future activities within the Waste to worth project will be focused on. So, the planned activities within our bioslurry project will be performed in accordance with the plans. The planned activities were as follows:

- Qualitative and if possible quantitative description of the amount of nutrient losses that might be expected from the production, handling, storage and application of bioslurry. Indication of the way those losses may be prevented or minimized by taking practical measures;
- Which variations in the composition might be expected and how can the composition of bioslurry be estimated?
- Make an estimation of the amount of nutrients that is required by specified crop-soil combinations in a number of regions and in dependence of climate and soil fertility;
- Determine the optimal application dose and way of application of bioslurry, based on its' composition, etc.

Figure 3.1. Example of an overflow of bioslurry storage in Kenya, leading to an uneven distribution of bioslurry (picture: dr. P. van Erp, Soil Cares Research).

4 Nutrient losses: what is the amount and how can they be reduced?

4.1 Nutrient losses during the bio-slurry production chain

The major steps in the bio-slurry production chain includes anaerobic digestion, handling, storage, transport and application. During each step, losses of nutrients (especially nitrogen) may appear from the bio-slurry. The risk for losses during the various steps are discussed in the following text.

4.1.1 Losses during the digestion process

During the digestion process, it is suggested that the losses of nitrogen (N) will be limited and can be neglected (Bonten et al., 2014). According to Möller et al. (2010) and Schievano et al. (2011) the N losses can be up to 5-10 % of the total N. In general, it is assumed that the amount of N losses during the anaerobic digestion process will be less than during composting (Smith et al. 2013).
However, as one of the most important nutrient elements for plants, N may easily get lost after it has been converted from organic into inorganic form (mainly NH_4^+). Due to the high proportion of NH_4^+ out of total N in the digestate, the N may easily get lost after the moment of collection from the digester and during the further process steps.

4.1.2 Losses during bio-slurry collection

No relevant publication has been found on the study of N losses during collection of bio-slurry. Due to the fact that N losses, especially by volatilization, are higher with the increase of contact area between manure/digestate surface with air, it can be assumed that during bio-slurry collection from the digesters, nitrogen losses through volatilization may be significant.

4.1.3 Losses during bio-slurry handling

<u>Separation into solid and liquid fraction</u>
Untreated bio-slurry can be used directly, but it can also be separated into a solid and liquid fraction. This will result in two fractions with a different composition: most of the organic matter and P will be in the solid fraction. The amounts of NH_4-N and K will be similar in the solid and the liquid fraction (Möller & Müller, 2012). The solid fraction can thus be characterized as an organic fertilizer comparable with solid animal manure, but with highly available N and P contents, having a high potential for N losses. Separated liquid fractions of digestate may be characterized as NK fertilizers similar to animal urine. Because 45-80% of the N in the liquid fraction is present as NH_4 (Möller & Müller, 2012), the N will be susceptible to NH_3 volatilization. For practical reasons, further treatments of these separated fractions are performed in some cases. Drying and composting of the solid fraction of the bio-slurry are examples of such subsequent treatments, which may lead to high losses. Sometimes, liquid fractions are discharged to public sewage systems because its' low nutrient contents, which directly leads to high nutrient losses (Vu et al., 2012).

<u>Drying</u>
In order to solve the inconvenience of storage and transport of bio-slurry with high moisture contents (over 90 %), drying of bio-slurry is sometimes practiced. Drying of bio-slurry can be achieved by simply drying under the sun, which is widely practiced in South Asia (Gurung 1997). The main advantage of drying bio-slurry is that it becomes solid and the volume is reduced, by which the storage and spreading

of bioslurry becomes easier (Gurung 1997). However, the N losses by the volatilization of ammonia (NH_3) in fresh bio-slurry can be up to 90 % of the total amount of N during the sun drying process (Gurung 1997). The emission of nitrogen from bio-slurry during the drying process results in a reduction of the fertilizer value of the final product. Therefore, drying should be avoided, to prevent high N losses from the bioslurry.

Composting

Composting is one of the optional treatments for the solid fraction after separation of bio-slurry. Due to the low C/N ratio and small amount of degradable material in bio-slurry, it is preferably mixed with other organic materials, such as straw, for an optimization of the composting process (Bonten et al., 2014). Generally, part of the nitrogen is getting lost by volatilization of NH_3 during composting (Bonten et al., 2014). The nitrogen losses from composting of raw manures may be up to 51% and will be high when the compost heaps are uncovered, which is mostly the case in Africa (Smith et al. 2014b). Bustamante et al. (2012) reported that the nitrogen losses from composting of solid bio-slurry were between 15-27 %. The amount of nitrogen losses during composting highly depends on the feedstock types, the temperature achieved during the process, as well as the degree of aeration (Kirchmann & Widén 1994; Eklind & Kirchmann 2000; Beck-Friis et al. 2000). When composting of bio-slurry is performed with materials with a high C/N ratio, such as vine prunings, the nutrient losses can be reduced by 5-15 % (Bustamante et al. 2012).

4.1.4 Losses during bio-slurry storage

Losses from bio-slurry storage may take place in various ways:

- Overflow of bio-slurry from the storage tank or lagoon;
- Gaseous losses;
- Leaching losses.

The storage of digestate or bio-slurry in uncovered tanks or lagoons will usually result in large quantities of gaseous losses, for instance, CO_2, NH_3, N_2O and CH_4, into the atmosphere (Menardo et al. 2011). The amount of gaseous loss is depending on the surface area of the digestate that is exposed to the atmosphere (Zenshan 2012). Tran et al. (2011) reported that the total amount of N that was getting lost during the storage of uncovered pig slurry during a period of 90 days in Vietnam was 60-70% of the total N content that was originally present in the slurry. Paavola & Rintala (2008) described that the losses of nitrogen from digestate can be up to 15 % during 3-11 months of storage.

Factors determining the amount of N losses by NH_3-volatilization are:

- pH (the higher the pH, the more NH_4 is converted into NH_3, because of the chemical equilibrium);
- Temperature;
- the ammonia concentration in the slurry;
- wind speed;
- Air refreshment (Sommer, 1997; Bonten et al., 2014).

Previous studies reported that when digestate is stored for a long period of time, the potential of nitrogen losses increases due to the ongoing decomposition process. The increasing risk of NH_3 losses during storage is caused by the reduction in the content of total solids in bio-slurry, which reduces the possibility for crust formation in bio-slurry (Smith et al. 2007).

It has been reported by many authors that the ammonia emission from slurries may be reduced significantly by various types of covers, such as closed covers or floating covers, including natural crusts. Van der Zaag et al. (2008) discussed the results from various studies on the effect of floating covers on the reduction of gas emissions from liquid manure storages in a review article. They concluded that the floating covers may significantly reduce N losses by NH_3 volatilization.

Results of various studies on the NH_3 volatilization from stored slurries, with or without a cover, were summarized by Bonten et al. (2014) and are given in Table 4.1. From those results it may be concluded that the N losses by ammonia volatilization may be significant (up to 70% of N in several months), and that covering the slurry may reduce the volatilization by a factor 2 - 20. As an example, Smith et al. (2007) found that the monthly relative loss of the initial nitrogen from uncovered storage of bio-slurry (4.4 %) was higher than that of bio-slurry stored with a cover of 15 cm layer of lightweight-expanded clay aggregates (0.9 %).

Table 4.1 Overview of N losses by NH_3 volatilization from covered and uncovered animal slurries, bio-slurries and other digestates during storage (Source: Bonten et al., 2014).

Source	Emission (g NH3 m^{-2} d^{-1}) or (% of total N)	Remarks	Reference
Uncovered pig slurry	2.0-3.1	Summer, Denmark	(Petersen et al., 2013)
Pig slurry covered with straw enforced crust	0.2-0.3	Summer, Denmark	
Uncovered bio-slurry	0-25	Min. at sub-zero temp., max. in summer period, Denmark	(Sommer, 1997)
Covered cattle slurry	1.05	80 days at app. 17°C, Austria	(Amon et al., 2006)
Covered bio-slurry from cattle slurry	0.25	80 days at app. 17°C, Austria	
Digestate from food waste	0.9		(Whelan et al., 2010)
Non-separated digestate	2.06-4.44	Season, Italy	(Gioelli et al., 2011)
Digestate liquid fraction	7.89-14.6	Season, Italy	
Covered pig slurry	25-30%	After 90 days, Vietnam	(Tran et al., 2011)
Uncovered pig slurry	60-70%	After 90 days, Vietnam	
Covered bio-slurry	0.03-0.15 g NH_3-N/kWh	Germany	(Liebetrau et al., 2013)[a]
Uncovered bio-slurry	0.2-3.7 g NH_3-N/kWh	Germany	

Next to gaseous N losses from bio-slurries during storage, nutrients may also get lost from bio-slurries by leaching from storages without an impermeable barrier at the bottom (Bonten et al., 2014). This will especially be the case for nutrients that are dissolved in the liquid fraction of the slurry, such as N and K (Massé et al., 2007).

Concluding:

- Nutrient losses from bio-slurry during storage may be significant and may take place via overflow of the storage, via NH_3 volatilization (N loss) and via leaching (mainly N and K).
- To prevent nutrient losses from bio-slurry during storage the following measures should be taken:

- The storage capacity should be sufficient to prevent overflow;
- N losses from bio-slurry by NH_3 volatilization should be minimized by covering the storage;
- Leaching of (nutrients from) bio-slurry should be preferably prevented by an impermeable barrier at the bottom of the storage.

4.1.5 Losses during and after bio-slurry application

During and after bio-slurry application to the field, nutrients can get lost via various processes:

- Gaseous N losses, especially by ammonia volatilization and denitrification or N_2O emission;
- Nutrient leaching by a surplus of water.

Especially, the N loss via NH_3 volatilization after the application of animal slurry and/or bio-slurry can be substantial. Several examples of studies in which the N loss by NH_3 volatilization is measured are given below:

- Amon et al. (2006) reported that the NH_3 and CH_4 emissions from dairy cattle bio-slurry after field application can be up to 220 g and 2.0 g per m^3 of the applied bio-slurry, respectively.
- Chantigny et al. (2007) studied the gaseous N losses from untreated and treated swine manure
- Möller & Stinner (2009) compared the N losses from various manuring systems.

The following factors are of relevance for the amount of N losses from slurry after its' application to the field:

- NH_4 concentration in the slurry;
- pH of the slurry;
- Ratio between solid and liquid parts of the slurry;
- Application rate;
- Way of application (widespread or injected into the soil);
- Eventual incorporation of slurry after its' application;
- Soil type and/or quality (e.g. clay and/or organic matter content);
- Soil moisture content;
- Air temperature;
- Wind speed.

Knowledge about the quantitative relations between the various factors affecting NH_3 volatilization and the total volatilization has been used for the development of models describing the NH_3 volatilization from animal slurries and/or bio-slurries. Examples of such models are the model of

- Gericke et al. (2012) and
- The Alfam-model (www.alfam.dk).

From the Alfam-model it becomes clear that:

- N-losses by NH_3 volatilization may be 50% of the total amount of NH_4-N in the slurry;
- The largest part of the NH_3 volatilization takes place within the first 24 hours after application;
- The NH_3 volatilization can be significantly reduced by
  - Dilution of the slurry, by which the dry matter content is reduced;
  - Direct injection of the slurry into the soil;
  - Cultivation of the soil after the application of the bio-slurry;
  - Application of the slurry during a period with little wind and low temperatures.

4.2 Methods to reduce the nutrient losses

As has been described in the foregoing, nutrients can get lost from the bio-slurry production chain. Summarizing, this can be the case during the following steps:

- Anaerobic digestion, which may lead to relatively low N losses by NH_3 volatilization;
- Handling, such as separation of slurry into a solid and liquid fraction, drying and/or composting of (the solid fraction of) bioslurry and/or disposal of the liquid fraction. The disposal of the liquid fraction will lead to high losses of nutrients, esp. N and K. Moreover, drying and composting may lead to high N losses by ammonia volatilization.
- Storage, which may lead to high nutrient losses by overflow of bio-slurry, if the capacity of the storage is not large enough. Moreover, N losses may take place by NH_3 volatilization (up to 70% of total N), which may be esp. high if the storage is not covered.
- Application: directly after the application of bioslurry, the risk for N losses by NH_3 volatilization is high and may be up to 50% of the total amount of NH_4-N in the slurry. The largest part of the NH_3 volatilization takes place within the first 24 hours after application.

The following measures could be taken to reduce nutrient losses from the bio-slurry production chain:

<u>Measures to reduce nutrient losses during anaerobic digestion</u>

The anaerobic digestion should be performed in closed systems, by which the nutrient losses are low, normally spoken. No additional measures are required during this stage of bio-slurry production.

<u>Measures to reduce nutrient losses during bio-slurry handling</u>

During the handling stage, it is of importance that all fractions of bioslurry are collected and no part (e.g. the liquid fraction) is disposed. Moreover, drying of untreated bioslurry or the solid fraction of bioslurry should be avoided. If bioslurry is composted, the bioslurry should be composted together with materials with high C/N-ratio (e.g. straw and/or woody material, such as prunings) to prevent N losses by NH_3 volatilization.

<u>Measures to reduce nutrient losses during bio-slurry storage</u>

Measures to reduce nutrient losses during the storage of bio-slurry are:

- The storage capacity should be sufficient to prevent overflow;
- N losses from bio-slurry by NH_3 volatilization should be minimized by closing or covering the storage;
- Leaching of (nutrients from) bio-slurry should be preferably prevented by an impermeable barrier at the bottom of the storage.

<u>Measures to reduce nutrient losses during and after bio-slurry application</u>

Possible measures to reduce N loss by NH_3 volatilization after the application of bio-slurry to the field are:

- Dilution of the slurry, by which the dry matter content is reduced;
- Direct injection of the slurry into the soil;
- Cultivation of the soil after the application of the bio-slurry;
- Application of the slurry during a period with little wind and low temperatures.

5 Determination of composition of bioslurry

5.1 Variations in the composition of bio-slurry

In a review about the effects of anaerobic digestion on the nutrient availability, an overview of variations in the composition of bio-slurry has been given (Möller & Müller, 2012; Table 5.1).

Table 5.1. Variations in the composition of digestate and change with respect to the composition of undigested animal manures (source: Möller and Müller, 2012).

parameter	value	change[a)]
Dry matter, DM (%)	1.5-13.2	-1.5 to -5.5
Organic matter (as % of DM)	63.8-75.0	-5 to -15
Total N (% of DM)	3.1-14.0	[b)]
Total N (g/kg FM)	1.5-6.8	≈ 0
NH_4 (% of total N)	44-81	+10 to +33
Total P (g/kg FM)	0.4-2.6	≈ 0
Water soluble P (% of total P)	25-45	-20 to -47
Total K (g/kg FM)	1.2-11.5	≈ 0
Total Ca	1.0-2.3	≈ 0
Total Mg	0.3-0.7	≈ 0
pH	7.3-9.0	+0.5 to +2 units

[a] in comparison to undigested liquid manure, absolute values

[b] increase with degree of degradation

DM = dry matter

FM = fresh matter

From a comparison of the composition of bio-slurry with undigested animal manures (Table 5.1) some conclusions can be drawn about the changes taking place because of the digestion process:

- Part of the organic matter is decomposed, resulting in a decrease of dry matter and organic matter;
- Ammonium (NH_4) levels are increased;
- pH is also increased because of the digestion process;
- the content of water soluble P is decreased;
- The total contents of nutrients (N, P, K, Ca and Mg) are not strongly affected.

Moreover, it becomes clear from Table 5.1 that the variations in the composition may be significant, and that the highest values of the reported nutrient contents are a factor 2-10 higher than the lowest values. Because the composition of bioslurry may be very variable, it is of importance to know that composition for its' optimal use. Various options to determine that composition (by estimation or measurement) will be explored in the following paragraphs.

5.2 Causes of variations in the composition of bio-slurry

Various factors affecting the composition of bio-slurry can be distinguished and are shortly summarized and discussed below:

- The composition of the feedstock, which is animal manure or animal slurry in most cases. The animal type, the housing of the animals and the feed which is supplied to the animals are important factors in determining the composition of the bio-slurry;
- Pretreatment of the feedstock, e.g. by mechanical smash, removal of physical impurities, homogenization, thermal hydrolysis, maceration and ultra sound treatments can enhance digestibility of organic matter by increasing the surface area. Moreover, a separation of feedstock (e.g. animal slurry) into a solid and a liquid fraction affects the composition of bio-slurry as well.
- The addition of materials (such as straw or maize silage; co-digestion) to the main feedstock (animal manure or slurry) will affect the composition of the resulting bio-slurry as well.
- The addition of water to the digester is often needed for the optimization of the digestion process, but of course results in a decrease of the nutrient concentration in the bio-slurry. The desired ratio between solid manure and water is about 1:1 (Pandey et al., 2007), but sometimes much more water is added (e.g. Vu et al., 2012), leading to very low concentrations of nutrients (15 times lower than in manure), which was the reason farmers in Vietnam discharged a large part of bioslurry into the environment (Vu et al., 2012).
- The conditions during the digestion process will also determine the composition of the resulting bio-slurry. Factors such as pH, temperature, mixing and the NH_3 contents in the digester will affect the composition of bio-slurry.
  - It is said that the pH value of the feedstock would have influence on the dissociation of compounds during the digestion process, which could for instance affect concentrations of ammonia, hydrogen sulphide and organic acids (Al Seadi et al. 2008). Nevertheless, no clear relationship was observed between pH of digestate and its' nutrient content.
  - The temperature setting during the digestion can be divided into three classes: psychrophilic temperature (<25 ℃), mesophilic (25-45 ℃) and thermophilic (45-70 ℃) (Al Seadi et al. 2008). Hao (2006) has reported that during the anaerobic digestion of pig manure, thermophilic digestion (52 ℃) resulted in higher total N losses than the digestion at lower temperatures, while it showed the highest increase of soluble P. The increase of available K was highest under mesophilic digestion (37 ℃) conditions. Overall, higher digestion temperature can result in higher decomposition rate and utilization of the raw materials by the microbes, which eventually causes higher variation of the nutrient contents in the digestate compared to its raw material (Hao 2006). Other studies also demonstrated that the thermophilic process could produce digestate with a relatively high quality, which can be used as fertilizer or soil amendment (Zenshan 2012).
  - Mixing will generally favour the digestion process and will thus lead to a more complete digestion.
  - High NH_3 contents will inhibit the digestion process, which may lead to uncomplete digestion (Liu et al., 2012; Zenshan, 2012).

As has been stated, part of the variation in the composition of bio-slurry may be caused by the type of animal manure that is used as a feedstock for the digestion process. Average nutrient contents of bio-slurries based on several types of animal slurry are given in Table 5.2.

Table 5.2. Average nutrient contents and chemical properties of bio-slurry from manure of different animals (sources: [1] Islam et al. 2008, [2]de la Fuente et al. 2012, [3]Möller et al. 2008, [4]Galvez et al. 2012, [5]den Toom 2013, [6]Islam et al. 2009, [7]Kirchmann & Witter 1992).

Parameter	Cattle	Pig	Poultry
pH	7.5-7.9[1 2 3 6]	8.5[4]	8.2[1] -8.3[6]
DM (%)	9.0[2] -9.2[3]	-	-
OM (% DM)	63.8[3]	75.5[4]	-
C/N ratio (of OM)	19.9[7]	21.3[7]	17.9[7]
Total N (mg g^{-1} DM)	13-15[5]	44[4]	18-27[5]
NH_4^+-N (mg g^{-1})	1.90 (in FM)[2]	5.36 (in DM)[4]	-
Total P (mg g^{-1} DM)	9.3[7]	19.7[7]	23.5[7]
Total K (mg g^{-1} DM)	12.9[7]	17.8[7]	24.1[7]
Ca (mg g^{-1} DM)	20.1[7]	34.2[7]	91.7[7]
Mg (mg g^{-1} DM)	6.4[7]	12.2[7]	6.1[7]
S (mg g^{-1} DM)	3.6[7]	4.6[7]	5.3[7]

From Table 5.2 it becomes clear that nutrient contents (esp. N, P and K) in bioslurries from pig and poultry manure are generally higher than in that from cattle manure.

Moreover, the feed composition will also affect the composition of animal manure and thus the resulting bio-slurry. This has been described by Vu et al. (2012), who compared the manure composition from pigs which were fed by different feeds. Manure from pigs fed by a higher proportion of commercial feed showed a higher N content compared to pigs fed with traditional feed, as a result of a higher protein content in the commercial feed (see Table 5.3).

Table 5.3. Nitrogen contents (g kg^{-1} DM) (average ± standard deviation) in different pig feeds and in solid manures of different pig breeds fed by variations of proportions of feed types (source: Vu et al. 2012).

Feed types	Traditional feed (T)	Commercial feed (C)	Mixed feed (M)
N content	23.1 ± 5.3	31.6 ± 21.4	28.4 ± 15.3

Pig breed	Piglet	Fattener	Sow
Feed type	25 % C + 75 % M	65 % C + 35 % M	25 % C + 35 % T + 40 % M
N content in solid manure	29.9 ± 4.0	52.2 ± 20.9	36.3 ± 16.6

Because the nutrient contents in animal feeds commonly used in Sub Saharan Africa (SSA) are relatively low, the total nutrient contents, and especially the directly available fraction of the nutrients in bioslurry, will be low as well (Smith et al., 2014). For N this will mean that the ratio between NH_4-N and total N will be relatively low.

5.3 Methods for the determination of the composition of bioslurry

Knowledge about the composition of bioslurry is very important for a sustainable use as a fertilizer, because that information is required for the optimization of the nutrient dose, preventing over and/or under application (e.g. Reeves, 2007). The composition of bioslurry may be determined with the following methods:

- Direct measurement with standard analytical procedures in the laboratory. This determination method will give the most accurate result of the contents of dry matter, organic matter and (fractions of) nutrients in bioslurry. In Kenya, there is a commercial lab that offers the possibility to analyze the composition of manure, including bioslurry (www.cropnuts.com). The results of such an analysis requires 10 days, which is quite a long time.

- Another possibility to get information about the composition of bioslurry is offered by the availability of quick tests for on-farm analysis of animal manures and/or bioslurries (e.g. Reeves, 2007; Martínez-Suller et al., 2010; Bicudo & Singh, 2007; Chen et al., 2014). An advantage is that the result of a quick test takes only a short time (preparation including measurement in general within 1 hour; sometimes calibration is required).
- Spectroscopy, for instance near- and mid-infrared reflectance spectroscopy (NIRS and MIRS, respectively) has become one of the most favorable rapid analysis methods in the laboratory and on-farm (Reeves 2007). The analysis of components by means of spectroscopy has been widely used on agricultural products, not only on manures and soils, but also on feeds, forages and grains (Reeves 2007).
- Estimations of the composition of bioslurry could be given at the basis of the average composition of feedstocks which are used for the digestion. However, this will probably lead to inaccurate numbers, because of large variations in the composition of feedstocks and effects of process conditions on the composition of the bioslurry.

In the following subchapters, the possibilities of some quick tests (subchapter 5.4) and of spectroscopy (subchapter 5.5) in relationship with standard laboratory analysis will be discussed.

5.4 Quick tests for the determination of the composition of bioslurry

5.4.1 Available quick tests

There are several types of kits which can be used as on-farm quick tests to determine the (liquid fraction of) bio-slurry composition: the hydrometer, the electrical conductivity meter and pen, the Agrose N meter, the Quantofix-N-Volumeter and the reflectometer (see Figure 5.1). The principle of the first two mentioned methods is based on the relationship between physicochemical properties (specific gravity and electrical conductivity) and the chemical composition. The Agrose N meter and the Quantofix are based on the reaction of chlorine bleach with NH_3 to produce N_2. The Reflectometer is a small portable spectrometer reading test strips which have been dipped into a sample (solution).

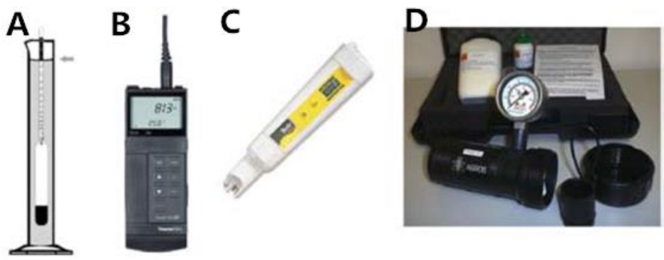

Figure 5.1. Quick test kits. A. Hydrometer. B. Conductivity meter. C. Conductivity pen. D. Agrose N meter (source: Bicudo 2006).

Hydrometer

The measurement with the hydrometer is based on the linear relationships between the specific gravity of the sample (which is measured), the dry matter content (DM) and the total N or total P contents. Combining the relationships gives a linear relationship between both total N and total P and the specific gravity of the sample (Tunney 1979; Tunney 1985). Before measuring, calibration curves should be developed relating specific gravity to DM and nutrient contents of the bio-slurry sample. When measuring the specific gravity of the samples, the hydrometer should be immersed into the sample immediately after mixing the sample, the reading should be taken within 10-30 seconds (Bicudo & Singh, 2007; Zhu et al., 2004). The hydrometer would not float freely in less liquid samples, which is required for a proper function of the meter. Therefore, most of the samples need to be diluted with adequate tap water.

With the specific gravity value obtained with the hydrometer, the DM and N, P contents of the sample can be estimated (Bicudo & Singh 2007). However, Reeves (2007) indicated that the results for N, P and K obtained with the hydrometer in 99 dairy manure samples collected in the northeastern part of the US were poor.

Electrical conductivity meter/pen

Electrical conductivity meter and pen are indirect methods for estimating nutrient contents (especially NH_4 and K) based on the linear relationships between ammonium and potassium ions and EC of the samples (Bicudo & Singh 2007). Traditional conductivity meters have a base meter and an attached probe which can be placed into the sample for measuring EC, in a similar way as with pH meters (Van Kessel & Reeves III 2000; Bicudo & Singh 2007). Based on the calibration curves developed ahead of the measurement relating EC to NH_4^+-N, the NH_4^+-N content in samples can be estimated (Bicudo & Singh 2007). Reeves (2007) showed high correlations between EC and NH_4 contents in 99 dairy manure samples measured by standard analytical test.

The operating ranges of the conductivity meter and pen are approximately 0 to 2000 µS cm^{-1}. Often, dilution of the samples will be required to fall within that range. As soon as the reading is stable (normally less than 30 s), the EC values can be recorded (Van Kessel & Reeves III 2000).

Existing kits for electrical conductivity measurement include conductivity meter (Fisher Scientific Pittsburgh, PA), conductivity pen (Cole-Parmer Instrument Co. Vernon Hills, IL), Hanna conductivity meter, Oakton Conductivity Tester, which can be purchased from general laboratory supply (Van Kessel & Reeves III 2000; Bicudo & Singh 2007).

Reflectometer

Ammonium concentrations can be estimated by the colorimetric reactions between Nessler's reagent and NH_4^+, of which the color intensity on the exposed test strip can be quantified visually (which is less accurate) or by the reflectometer (such as the one manufactured by Merck, Germany) (Van Kessel & Reeves III 2000).

Bioslurry and manure samples should be extracted with Potassium Chloride (KCl) and filtered before the measurement can be performed (Figure 5.2). The procedure of estimating the NH_4^+-N concentration of samples by a visual evaluation or using the reflectometer is illustrated in Figure 5.3.

Samples with high NH_4-concentrations should be diluted in order to meet the operating range of 20 to 180 mg NH_4^+-N/l of the instrument and test trips (Van Kessel & Reeves III 2000).

Reeves (2007) showed a high correlation coefficient (R^2) of 0.90 between measurements of NH_4 with the reflectometer and standard analytical procedures, which were performed in 99 dairy manure samples collected in the northeastern part of the US. The results for total N were lower, but still quite high (R^2= 0.70).

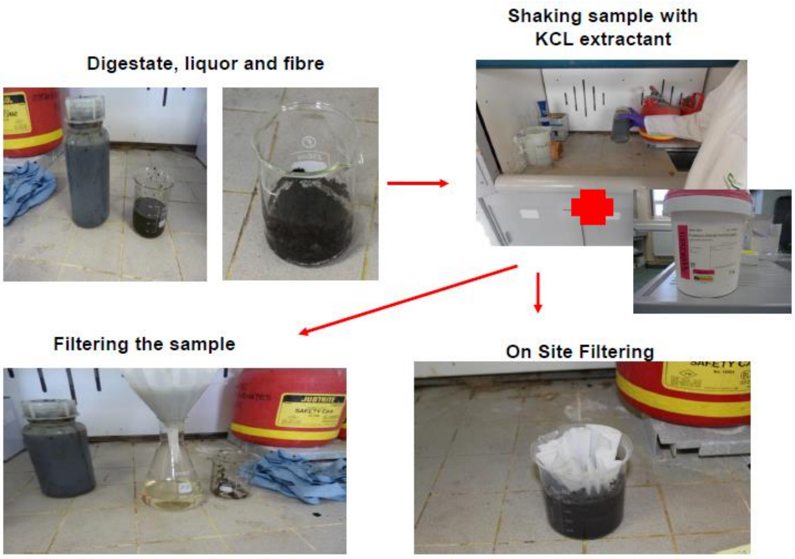

Figure 5.2. Sample preparation by extraction and filtration of digestate, before the ammonium concentration can be determined with test strips (source: Prasad et al. 2013).

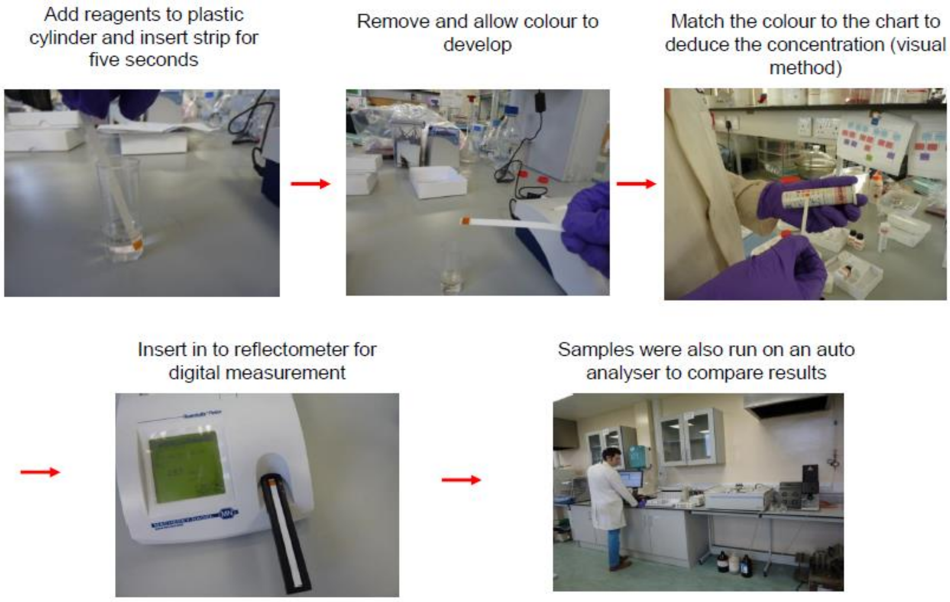

Figure 5.3. Procedures for examining the ammonium strips visually and for using the reflectometer (source: Prasad et al. 2013).

Agros N meter

The Agros N meter has been tested and used in the United States and Europe, which is operated based on the reaction between NH_4^+ with hypochlorite, the NH_4^+ is oxidized and N_2 (gas) is produced (Chambers 1998; Chescheir III et al. 1985; Van Kessel & Reeves III 2000; Bicudo & Singh 2007). When measuring, the samples are mixed with a powdered reagent containing calcium hypochlorite ($Ca(ClO)_2$), calcium chloride ($CaCl_2$) and calcium hydroxide ($Ca(OH)_2$) in a sealed chamber, the N_2 gas which is produced can be measured with a pressure gauge (Van Kessel & Reeves III 2000; Bicudo & Singh 2007). The NH_4^+-N concentration in the samples can be estimated based on the calibration curves relating the pressure gauge value to NH_4^+-N (Bicudo & Singh 2007). Studies has demonstrated that the reaction in the chamber is complete after 5 min, thus the reading of the values needs to be recorded after 5 min of mixing the chamber.

Reeves (2007) showed a rather high correlation coefficient (R^2) of 0.78 between measurements of NH_4 with the Agros meter and standard analytical procedures, which were performed in 99 dairy manure samples collected in the northeastern part of the US. The results for total N were similar (R^2= 0.78).

Quantofix-N-Volumeter

The Quantofix-N-Volumeter has the same principle as the Agros N meter, which is mostly used in Europe (Van Kessel & Reeves III 2000; Chambers 1998). A liquid mixture of sodium hypochlorite (NaClO) and sodium hydroxide (NaOH) is used as the reagent for the meter. The meter has a reaction chamber which is attached to a water-filled base. The NH_4^+-N concentration in the samples can be estimated based on the calibration curves relating the produced N_2 gas to NH_4^+-N (Van Kessel & Reeves III 2000).

Reeves (2007) showed a high correlation coefficient (R^2) of 0.94 between measurements of NH_4 with the Quantofix N-Volumeter and standard analytical procedures, which were performed in 99 dairy manure samples collected in the northeastern part of the US. The results for total N were lower (R^2= 0.58).

5.4.2 Evaluation of the available quick test methods

Accuracy

Compared to laboratory analysis methods, an analysis with on-farm quick test kits take less time. On the other hand, not all quick tests are easy to handle and normally their results are less accurate. Table 5.4 provides the parameters which can be determined by different kits, with the coefficients of correlations (R^2) of these methods. A higher value of R^2 indicates that the test result is more accurate in relation to the laboratory analysis.

Table 5.4. Quick test methods for monitoring bio-slurry composition and the coefficient of correlations (R^2) of these tests in relationship with laboratory tests (sources: [1] Bicudo 2006, [2]Van Kessel & Reeves III 2000, [3]Reeves 2007).

Kit	Parameter	R^2		
		Dairy manure	Low DM (≤ 12 %) manure[2]	High DM (> 12 %) manure[2]
Hydrometer	TS	0.76-0.81[1]	-	-
	Total N	0.40[3]-0.89[1]	0.48	-
	Total P	0.93[1]	-	-
Conductivity meter	NH_4^+-N	0.70[1]-0.86[3]	0.89	0.86
Conductivity pen	NH_4^+-N	0.67[1]-0.84[3]	0.87	0.83
Agros N meter	NH_4^+-N	0.66[1]-0.79[3]	0.81	0.69
Reflectometer	NH_4^+-N	0.90[3]	0.91	0.87
Quantofix-N-Volumeter	NH_4^+-N	0.94[3]	0.95	0.92

In general, the quick test kits are somewhat more accurate for measuring liquid slurries than solid manures (see Table). Most quick tests can only be used for the determination of NH_4 and the hydrometer is the only quick test in the overview of Table 5.4 that may be used for measuring total N and P. However, its' lack of accuracy requires improvement (Van Kessel & Reeves III 2000). In contrast with the data from Table 5.4 Reeves (2007) states that no quick test has been found that can accurately determine the P content of manure (Reeves, 2007).

For other quick tests which can be used to estimate NH_4^+-N concentration, the Quantofix-N-Volumeter is suggested to be the most accurate way for both liquid and solid samples. Other possible and well-performed methods are the Agros N meter and reflectometer for measuring liquids, as well as the conductivity meter and pen for measuring both liquid and solid samples (Van Kessel & Reeves III 2000). These findings led to the conclusion of Reeves (2007), who has indicated that the presently available quick tests are only accurate in determining the NH_4^+-N concentration in dairy and poultry manure, and that the results of organic N and P contents in manures obtained by quick tests are less satisfactory.

Moreover, the precision of the estimated linear regressions is related to the nutrient contents in samples. Even with a high coefficient of correlation for the linear regression, the error in the estimation can still be significant (Zhu et al. 2004). The authors mentioned that with the decrease in nutrient concentrations in samples, there will be an increase in the error of the estimation. Therefore, samples which are highly diluted may result in inaccurate estimations of the total N and P contents in samples (Zhu et al. 2004).

Furthermore, due to the differences in manure type, handling, management, feeding rate of livestock, etc. it is suggested that the precision of the estimations based on the quick test methods can be increased if the calibration curves are developed for specific conditions within a specific region, for instance, an individual farm (Singh & Bicudo 2005). Therefore, the results of the measurement of nutrient (esp. NH_4-N) contents in bio-slurry estimated by the quick test methods will be more accurate if the calibration curves are developed for uniform conditions (e.g. similar feedstock and process conditions).

Costs for the purchase and use of the quick test kits

The costs for the quick test kits are built up of costs for the purchase of the kits and cost per sample for its' use. An overview of the indicative costs is given in table 5.5. Actual costs for the purchase of the quick test kits should be obtained from the producer or dealer in your country. For almost all of these test kits, it can be concluded that the costs per sample will be relatively low.

Table 5.5. Indicative costs for purchasing quick test meters and for the analysis.

Quick test kit	Cost for meter	Cost for analysis	Reference
Hydrometer	$40	Little/no	(van Kessel et al. 1999)
Conductivity meter	$400-1000	Little/no	(van Kessel et al. 1999)
Conductivity pen	<$150	Little/no	(van Kessel et al. 1999)
Reflectometer	€500	<€2 per sample	(Prasad et al. 2013)
Agros N meter	$335	Reagent refills: $50	(Bicudo & Singh 2007)
Quantofix-N-Volumeter	$330	<$1.2 per sample	(van Kessel et al. 1999)
Ammonia electrode	$2000	<$1.2 per sample	(van Kessel et al. 1999)

Advantages and disadvantages of quick tests

Summarizing, the quick tests for the determination of the composition of bioslurry which are discussed in the foregoing subchapter have the following advantages:

- They can often be used on farm, and it is not necessary to send samples to the laboratory;
- Results are generated within short time (after calibrations have been performed);
- Costs are relatively low;
- Variations in the composition of bioslurry can be taken into account, because a lot of samples can be taken.

However, also some limitations or disadvantages are associated with the quick tests:

- In fact, only ammonium-N (NH_4-N) can be measured accurately with the available techniques;

- In most cases, calibrations are required with traditional analytical methods, which require more effort, expressed in time and money;
- Sometimes, dilution or extraction is required to prepare a sample before it can be measured with the available technique;
- In most cases, the techniques are not suitable for use by the farmer himself. So, some level of organization is needed for making the method available for the farmer.

5.5 The use of Near-infrared spectroscopy to determine the composition of bioslurry

Principle and advantages

The use of near-infrared spectroscopy (NIR) for the determination of the composition of bioslurry is based on light absorption at near-infrared wavelengths by the constituents in the samples (Reeves and van Kessel, 2000). NIRS is suggested to be an alternative way to determine manure nutrient concentrations, which can provide fast and accurate results, and can also be a potential method for making estimation of bio-slurry composition (Ye 2003). NIRS can be used for quick determinations of total N, total C, ash content, total solids (TS), potassium (K), ammonium (NH_4^+-N) in a large range of manure samples, for instance, cattle manure compost, solid beef manure, dairy manure, poultry manure and pig manure (Asai et al. 1993; Malley et al. 2002; Millmier et al. 2000; Nakatani et al. 1996; Reeves III & Van Kessel 2000b; Reeves III 2001). NIRS is combined with applied spectroscopy and statistics, the technique is rapid and nondestructive and usually does not result in chemical waste production (Williams & Norris 2001; Ye 2003). Originally, NIRS measurements were especially performed in laboratories, but portable or mobile NIR instrumentation has been introduced for on-farm analysis (Case 1999).

Summarizing, the most important advantages of the NIRS-technique are (Chen et al., 2014):

- It supplies a rapid analysis;
- It requires (almost) no sample preparation;
- It does not generate chemical waste;
- It can evaluate several components simultaneously;
- Measurements can be performed on-farm.

Calibration and statistical models

The NIRS-technique is based on the development of calibrations relating the spectral signature of manure components to the nutrient concentrations, which do not involve chemical reactions or extractions (Millmier et al. 2000; Reeves III & Van Kessel 2000b; Reeves III & Van Kessel 2000a; Malley et al. 2002). For spectral analysis of animal manures, reflectance and transflectance modes are applied. This has been discussed by Chen et al. (2014). For calibrations, sophisticated statistical techniques are used, which lead to calibration models (Chen et al., 2014). There are several valid types of statistical calibration models that can be used for the calibration of NIRS measurements, i.e. multiple linear regressions (MLR), Principle component analysis (PCA), principle component regression (PCR), partial least square (PLS) and artificial neutral networks (ANN) (Millmier et al. 2000). Based on the performance of those calibration models, conclusions can be drawn about the accuracy with which a component can be determined by the NIRS method. A lot of effort has been paid to the further development and improvement of statistical techniques to improve the predictions of the composition of manures (e.g. Chen et al., 2009; 2010).

Spectroscopy methods and accuracy

Spectroscopy methods are conducted under the spectral range of visible (400 nm) to the MIR (25,000 nm). Generally, NIRS refers to the work that involves the visible to shortwave NIR (400-1100 nm) range, with or without the combination of the NIR (1100-2500 nm) spectral range (Reeves, 2007). While MIRS is based on the spectral range of 2500 to 25,000 nm (Van de Leuven, 2006).

The accuracy of spectroscopy compared to laboratory analysis results is determined by several factors. For instance, the crucial technical parameters, such as light source and detector, measurement principle, wavelength range and resolution, have great influence on the precision of the results (Mouazen et al., 2005).

Two types of chemical constituents in animal manures can be accurately predicted with NIRS (Sayes et al., 2005; Chen et al., 2014). The first type of constituents can be directly assigned to main NIR absorption bands and thus have satisfactory predictions, which includes moisture content and dry matter content (DM), organic matter (OM), carbon (C) and nitrogen (N). The second type of chemical constituents, such as P and Mg, do not have spectral absorption bands, but can be predicted based on their correlations with DM content. This has been observed in a study performed by Saeys et al. (2005).

NANOBAG® method

A special test method based on NIR for the analysis of animal manure has been developed as NIRS-NANOBAG®, which makes the shipment of liquid manure easier and more hygienic (Wenzl 2010). The use of NANOBAG® can also ensure the stability of the samples during transport. The NIRS measurement is often conducted in labs, while during transport of manures, especially in liquid form, the nitrogen in manures is easily lost and causes environmental problems. The NANOBAG® can provide a safe condition for transporting liquid manure and liquid bio-slurry samples from fields to labs.
When sampling the liquid manures or bio-slurry in liquid form, the homogenized liquid manure can be simply added to a sample bag that contains carrier substance by using a beaker (see Figure 5.4.A). The carrier material of the NANOBAG® consist of an activated mineral, clinoptilolite zeolite, which has a nanoporous crystal structure (diameter of pores: 0.4 nm, inner volume per cm^3: 0.47 cm^3). The activated mineral can hold on the fluid and absorb all nutrients in liquid samples, which is especially of relevance for the volatile ammonia in the alkaline region (75 % of all liquid manure has an alkaline pH value). After samples has been sent to the laboratories, the mixture of carrier material and liquid samples will be desiccated and homogenized (see Figure 5.4.B), and subsequently be measured in the NIR spectrometer (see 5.4.C) (Wenzl et al. 2010; Wenzl 2010; Wenzl et al. 2013).

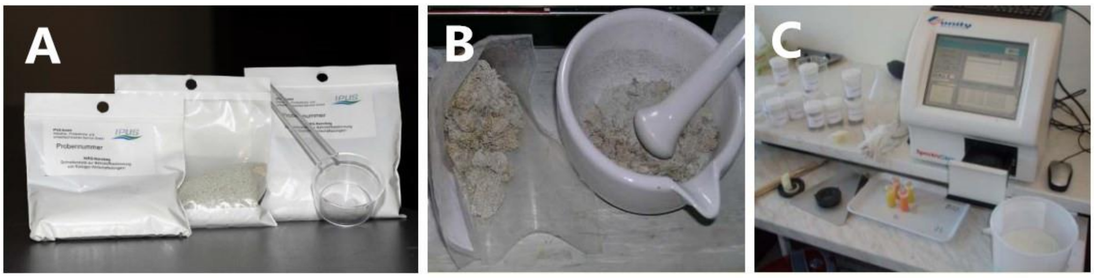

Figure 5.4. Procedures of bio-slurry sampling by NANOBAG®. A. NANOBAG® with carrier materials and measuring spoon. B. Desiccation and homogenization of samples by using NANOBAG®. C. NIR-spectrometer, LFZ Raumberg-Gumpenstein (sources: Wenzl et al. 2010; Wenzl et al. 2013).
A study has been done on the accuracy of the NIRS test combining with the use of NANOBAG® (Wenzl

2010). As shown in Table 5.5, the prediction models have good correlations on different liquid manures, as well as on the biogas liquid manure, except for the ash content. A comparison of the nutrient components in liquid manures measured by the NIRS-NANOBAG® with lab tests is shown in 5.6, which indicates that this new technique for determining nutrient contents in liquid manure and liquid digestate is effective, especially for total N and ammonium.

Table 5.5. Coefficient of correlations (R^2) and standard errors of prediction (SEP) between the variations of different liquid manure samples determined from laboratory tests and NANOBAG tests by using NIR spectrometers (source: Wenzl 2010).

Variation ($g\ kg^{-1}$)	All samples		Biogas liquid manure		Cattle liquid manure		Pig liquid manure	
	R^2	SEP	R^2	SEP	R^2	SEP	R^2	SEP
DM	0.863	3.45	0.810	3.81	0.787	2.47	0.843	2.47
Total N	0.918	0.16	0.941	0.13	0.910	0.11	0.929	0.15
Ammonium	0.888	0.09	0.952	0.06	0.782	0.07	0.883	0.09
Ash	0.767	0.96	0.682	1.08	0.501	1.18	0.819	0.80
P	-	-	-	-	0.926	0.080	0.990	0.143
K	-	-	-	-	0.883	0.555	0.941	0.195
Ca	-	-	-	-	0.894	0.172	0.877	0.365
Mg	-	-	-	-	0.967	0.057	0.972	0.147

Table 5.6. Comparison of the average values of 96 test samples derived by wet chemical analysis and by NIRS-NANOBAG® (source: Wenzl 2010).

Analysis method	**DM**	**OM**	**N**	**NH_4^+-N**
Wet chemical analysis	4.87	3.62	0.24	0.11[1]
NIRS-NANOBAG®	4.37	3.51	0.21	0.083[2]

[1] Direct alkaline KJELTEC™ distillation, [2] according to NESSLER.

The NIRS-NANOBAG® can give a proper estimation on DM, total N, NH_4^+-N, urea, ash, Ca, Mg, K and P contents in liquid manures and liquid digestate. It can be used to compensate the shortcomings of quick test methods, for they often cannot provide estimations on total N, P and K content. Moreover, by using a NANOBAG®, high costs for preservation of liquid manure during transportation can be overcome.

Evaluation of the possibilities of NIRS to determine the bioslurry composition

It can be concluded that most chemical constituents of animal manure can be predicted accurately by NIRS techniques, whereas P and metals require further research to improve their related predicted precision (Chen et al., 2014).

So, the advantages of NIRS with respect to more traditional determination methods are the fact that more nutrients can be determined and that the precision is higher, generally.

Before NIRS can be used in practice, a calibration for a specified product is required. A minimum dataset that is required for such a calibration is about 100 samples. Based on the quality of the predicted parameters, a selection for parameters could be made for practical applications.

Generally, NIRS sensors which are used in the laboratory, supply more precise information than NIRS sensors in mobile instruments.

5.6 Overall conclusions about the composition of bioslurry

- The composition of bioslurry may vary enormously: variations in dry matter, N, P and K contents may be up to a factor 10 or higher.
- Most important reasons for the variation are differences in feedstock (e.g. different types of animal manure, with or without urine, other additions, etc.), process conditions and dilution with water.
- For an effective and sustainable use of bioslurry as a fertilizer, it is crucial to know its' composition. If that is not known, several options are available for a determination: i) standard laboratory analysis, ii) estimation of the composition with quick tests and/or iii) by spectroscopy.
- Quick tests can only be used for the determination of the ammonium (NH_4) content of the bioslurry. Several quick tests are available for a rather accurate determination.
    - Advantages are that they are rapid, cheap and they can be performed on-farm.
    - Disadvantages are that they are limited to one parameter (NH_4), they require some handling (e.g. extraction and/or dilution) that cannot always be performed by a farmer and, often, calibrations are required with traditional analytical methods.
- Spectroscopy may also be used to determine the composition of bioslurry. It can be concluded that most chemical constituents of animal manure can be predicted accurately by NIRS techniques, whereas P and metals require further research to improve their related predicted precision. Before NIRS can be used in practice, a calibration for a specified product is required. A minimum dataset that is required for such a calibration is about 100 samples. Based on the quality of the predicted parameters, a selection for parameters could be made for practical applications.

6 Nutrient requirement of crops and possibilities for bioslurry in Kenya

6.1 Importance of soil quality and nutrient availability for crop growth and yield

Soil quality is playing an important role for crop growth and yield, because nutrients and water are supplied by the soil, which is essential for the conversion of CO_2 by solar radiation in plant material (mainly carbohydrates). Within this scope, physical, biological and chemical soil factors are of relevance:

- Physical factors are of importance because they are affecting the water holding capacity, the drainage properties, soil structure and associated workability, aeration, etc. In certain clay soils (e.g. with high % of montmorrillonite-clays, such as vertisols) the swell and shrink properties of the clay may hamper root development.
- Biological factors are of importance because of the important role of soil organisms for the recycling of nutrients, by the decomposition of organic matter. This is especially of importance for nitrogen (N), phosphorus (P) and sulphur (S), which are part of constituents of organic matter. Moreover, if the community of soil organisms is unbalanced, the sensitivity of plants for pathogens and/or soil borne diseases may be relatively high.
- Among the chemical factors, the availability of nutrients for crop growth is directly of influence for crop growth. Essential nutrients are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulphur (S) (the so called macronutrients) and iron (Fe), manganese (Mn), molybdenum (Mo), copper (Cu), boron (B) and zinc (Zn) (the so called micronutrients). This availability is not only affected by the total amounts of the nutrients in soil, but also by the form of nutrients in soil. In this respect, the distribution of nutrients over organic and inorganic forms and the distribution of cations over the soil solution and adsorption sites of organic matter and clay minerals (cation exchange capacity or CEC) is of relevance. Moreover, the chemical form of nutrients in the inorganic pool may strongly vary by e.g. pH and determine its' availability. The total concentration of nutrients or other salts in the soil is a chemical aspect that may hamper crop growth because the sensitivity of crops for high salt concentrations in the soil solution. The risk for those situations will be high in (semi) arid regions, especially if sensitive crops are grown.

The amount of nutrients that is required by crops depends on the crop type, the desired crop yield, the climate and/or weather conditions, the soil type and the nutrient supply by the soil. Nutrients are building blocks of plant constituents and/or they are playing a key role in the execution of various physiological processes op plants. Fertilizer recommendations are developed to supply guidelines for the amount of nutrients that is required in a specific situation. The objective of fertilizer recommendations is twofold:

1. The diagnosis and prognosis of the need for an additional nutrient supply in a specific situation, based on the nutrient supply by the soil and the nutrient requirement by the crop;
2. The supply of guidelines and/or directions for the amounts of nutrients that are needed. In addition to this second objective, it might be useful to supply guidelines about the optimal place, time and form (fertilizer choice) for the application of the nutrients.

Moreover, guidelines for the optimal fertilizer application are required both for agricultural / economical and environmental reasons. From an economical point of view to supply the right nutrients in the right amount, to obtain the economic optimum yield. From an environmental point of view it is of importance to prevent over application of nutrients, which may lead to leaching losses to ground and surface water and/or to gaseous losses to the atmosphere.

Because of the dependency of the nutrient requirement to environmental conditions, fertilizer recommendations are often developed for specific agro-ecological zones, in which the agricultural (soil and landform) and climatic conditions are more or less similar. The particular parameters used in the definition of agro-ecological zones focus attention on the climatic and edaphic requirements of crops and on the management systems under which the crops are grown. Each zone has a similar combination of constraints and potentials for land use, and serves as a focus for the targeting of recommendations designed to improve the existing land-use situation, either through increasing production or by limiting land degradation.

Generally, fertilizer recommendations are based on pot and/or field experiments, in which empirical relationships between the nutrient status of the soil, the nutrient supply by fertilizers and crop yield and quality are investigated. This is of importance, because soils differ widely in the capacity for providing nutrients, depending on the amount of total reserves, on mobilization or fixation dynamics and accessibility of the chemically available nutrients to the plant roots. The required pot and/or field experiments are often performed by Advisory Services and/or Research Institutes. However, this kind of research requires a lot of effort and money and is not performed everywhere and for all crop-soil combinations. In those situations, fertilizer recommendations are often based on very general crop-specific guidelines, or, more often, just do not exist (Schnier et al., 1997). In Kenya, until 1994, only three different fertilizer recommendations for maize existed in the whole country and mainly one nation-wide recommendation for all other crops (AIC, 1981). This was the reason for the establishment for a comprehensive fertilizer use research programme for rain-fed annual crops in the medium and high rainfall area of Kenya in order to establish crop and site specific fertilizer recommendations (Schnier et al., 1997; FURP, 1987).

In situations in which no relationships between nutrient status of the soil, nutrient supply by fertilizers and crop performance are available, recommendations about the required nutrient or fertilizer application in a specific situation (combination of crop and soil) will often be based on local experience or general data for crop requirements. If sufficient information is available, the (plant available fractions of) nutrient contents in the soil, may be used (together with pH, salinity, etc.) as an indicator for the nutrient requirement in a specific situation. Especially for perennial crops, the nutrient contents in plant(s) (parts), may also be used as an indicator for the required nutrient application.

6.2 Agro-ecological zones in Kenya

Kenya lies on the east of Africa, and is on the equator with the Indian Ocean to the south-east (see Figure 6.1). The country has low plains on the coast, highlands on the central, with fertile plateau on the east. Due to its variable geographic conditions, Kenya has a warm and humid climate along the coastline and around Lake Victoria, with cool climate in areas closer to Mount Kenya. There are two rain seasons in Kenya, from March/April till May/June, and from October till November/December, when the temperature is usually high.

Figure 6.1. Map of Kenya.
(source: http://www.glpinc.org/Graphics/Project_Sites/Africa/Kenya/Kenya-overview.htm).

Agriculture is an important sector for economics in Kenya. Kenya has a land area of around 60 million ha, of which 48.4 million ha is classified as arid and semi-arid lands. Arable land covers 16 % of the total land area (IFDC, 2012). There is a wide range of soil types in Kenya, varying from sandy to clayey, from low to high fertility. The occurring soil types are shortly described for the humid, sub-humid and semi-arid regions. This information is obtained from Orodho (2003).

Humid regions (The highlands)

These are areas with an attitude of over 1500 m which receive an annual rainfall of over 1000 mm. They have volcanic rocks and the soils are mainly loamy, and include the highlands east and west of the Rift Valley and the Rift Valley floor. Other humid areas with an altitude less than 1500 m (humid lowlands) have sandy soils which are well drained and are of loamy, sandy clay texture e.g., along the Kenyan coast. The Taita Hills have fertile loam soils which are agriculturally productive. Alluvial soils (silts) are found along river valleys e.g., Tana and Sabaki Valleys. Sand dunes and mangrove swamps are found along the coast. The soils covered by mangrove swamps are deep, grey, saline and poorly drained.

Sub-humid regions (Lake region and western Kenya)

These areas receive slightly less rainfall than the humid areas. They have volcanic and basement rocks. They lie between 1000 to 2000 m. Rainfall is up to 1,000 mm per year and soils are red clay. Areas with sedimentary rocks occur in the lowlands at an altitude ranging from 1,000 m and have loamy sandy soils. Soils here vary greatly according to the prevailing parent material. In higher regions, soils are dark red clays which are fertile and well drained. In the Kavirondo Gulf, soils are sandy loam formed from sedimentary rocks. Alluvial deposits of eroded material from uplands are common along flood plains of rivers such as Nyando, Yala, Nzoia, and Kuja. In plains such as the Yala and Kano plains, peat swampy soils and black cotton soils dominate. Volcanic soils interspersed with fertile peat swampy soils are found in the uplands. Soils in these regions are generally productive.

Semi-arid regions (northern and north-eastern Kenya)

These regions receive on average 300-500 mm of rainfall per year and the soils are shallow and generally infertile, but variable. These soils have developed mainly from sedimentary rocks. Areas with an altitude above 1,200 m and receiving rainfall of up to 600 mm e.g., Marsabit, have fertile volcanic soils. To the north-east of Horr, black cotton soils are found. These soils become water-logged when it rains. Around Lake Turkana, the soils are dark red in colour. In north-western Kenya, and to the east of Lake Turkana, there are lava soils. These areas receive less than 250 mm of rainfall per year and soils are not fully developed because they lack vegetation or organic matter. Along the Turkwell and Tana River basins, the soils are alluvial.

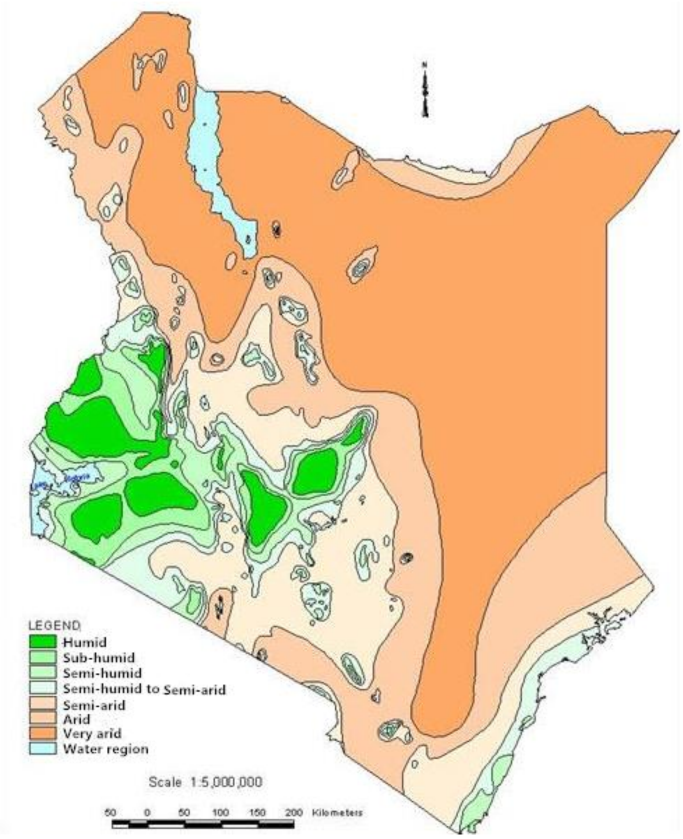

Figure 6.2. The agro-climatic zones of Kenya (source: infonent-biovision 2012).

Most of the soils in Kenya have serious limitations for agricultural use due to the salinity, acidity and drainage problems, with deficiency in N, P and K (Orodho 2003; Gachene & Kimaru 2003). The problematic soils are mainly located in the semi-arid and arid regions (ASALs) in Kenya (see Figure 6.2), which lie in the north and northeastern part of the country. The surface area of these regions is about 80 % of the total surface area of Kenya (infonent-biovision 2012), and that is unsuitable for rain fed cultivation, because of low and erratic rainfall (100-900 mm y^{-1}) and high evapotranspiration rates (Njeru et al. 2013). These conditions make the soils easily weathered and interferes with nutrient uptake by plants. In arid areas, the low amount of rainfall leads to low organic matter content in soils (Orodho 2003).

Soil fertility declines as a consequence of a combination of soil erosion, nutrient leaching and cultivation without adequate fertilization (Okalebo et al. 2006), which causes the decline of land productivity. This has resulted in a large yield loss in crop production in Kenya, such as in maize production (Mucheru-muna et al. 2014). Improving soil fertility and enhancing crop production can be achieved by combining the use of moderate and sufficient organic and mineral fertilizers. As in many countries in SSA, local production of fertilizers in Kenya is limited or non-existent, which makes it highly dependent on the international markets. Despite of the small market size for fertilizer in Kenya, the unnecessary product differentiation, the high cost for transport and handling fertilizer from the port, and the poor dealer network all result in low fertilizer use in Kenya's agriculture (Morris et al. 2007). Most of the consumed fertilizers is purchased by commercial farmers, while 70 % of the cultivated land is owned by smallholders who cannot afford for the fertilizers (IFDC 2012). Therefore, organic manures or fertilizers are quite important for the nutrient supply to crops in Kenya.

6.3 Nutrient requirement of maize in Kenya

The major crops for domestic consumption in Kenya are maize and wheat. Moreover, beans, peas, pulses and root crops (e.g. potatoes) are also important staple crops. Tea, coffee, sugarcane and banana are important cash crops. The cultivation areas and yields of these major crops in Kenya are listed in Table 6.1.

Table 6.1. Cultivation areas (in ha) and yields (in ton ha^{-1}) of the major crops in Kenya in 2013 (source: FAOStat, 2013).

	Maize	Dry beans	Wheat	Cow pea	Pigeon pea	Potato	Tea	Coffee
Area	2,028,202	1,030,435	131,309	192,345	144,218	152,007	198,600	110,000
Yield	1.67		3.7			14.43		0.36

From Table 6.1 it can be concluded that the cultivated area with maize is by far the largest area of the food crops cultivated in Kenya. The most important reqion where it is produced is the Rift valley. Moreover, it becomes clear that the yield level is quite low, as compared to the potential yield (about 5 tons per ha according to Ademba et al., 2014). In Kenya, maize is not only used for human consumption, but also the stalks, leaves and other remains are used for feeding domestic animals (Gachie, 2014). As a contribution of less favorable weather patterns and the decline of soil fertility, maize yield is constantly dropping in the recent years. Pests and disease attacks have caused great loss in maize grain yields, while the prolonged planting of maize also led to soil exhaustion (Gachie, 2014). Low pH value of the soils is a major constraint for maize production in Kenya, due to the toxic level of aluminium (Al) that inhibit plant root growth (Gudu et al., 2002). Moreover, the N and P deficiencies in many soils has limited the production of maize in western Kenya (Wasonga et al. 2008). Due to the low use of fertilizer, poor weed control and lack of quality seeds, the maize yields for smallholders in Kenya range from 0.5 to 1.5 ton/ha (IFDC, 2012).

The nutrient requirement of maize depends on the nutrient supply by the soil and by the uptake of the crop that is required to attain the desired yield and by. IFA (1992) supplied fertilizer recommendations for maize grown in South Africa with different yield levels (table 6.2).

Table 6.2. Fertilizer recommendations for maize in South Africa (IFA, 1992).

Yield level, t/ha	Recommended nutrient application		
	N	P_2O_5	K_2O
2	20	45	30
3	45	100	45
8	170	300	120

For Western Kenya, the blanket fertilizer recommendation for maize was 40 kg N and 60 kg P_2O_5 per

hectare (Schnier et al., 1997), before an extensive research program was started, in which 70 long-term fertilizer trials with rain-fed annual crops in the medium and high rainfall area of Kenya were started in 1987 (Schnier et al., 1997; FURP, 1987). This has resulted in crop and site specific fertilizer recommendations, but the relationships were quite complicated. About 50% of all sites with maize responded to a P application (during both long and short rainy period) and 75% responded to N application (during long rainy period).
Recently, recommendations were formulated at the level of county and sub county, at the basis of the analysis of 9.600 soil samples, taken from 4.800 farms, spread over 164 sub counties in Kenya (NAAIAP, 2014). The recommendations existed of required doses of manure, lime and fertilizers, taking into account the results of soil analyses, such as pH and nutrient supply. For example, the recommended application in Kisii Central (sub county within the Kisii county) is 1.000 kg of lime, 6 tons of manure, 250 kg of NP 23+23 and 125 kg of CAN.

Smaling et al. (1992) found that the response to N-, P- and/or K-application strongly differs between sites. Of the three sites studied, the maize in one site strongly responded to P, in another site it strongly responded to N and at the third site, it strongly responded to N and P. At the site where maize yield strongly responded to P, there was also found a strong response to animal manure.

Wasonga et al. (2008) performed field experiments with maize, to which different amounts of P fertilizer were applied on P deficient soils in Western Kenya. In most areas in Kenya the production of maize is constrained by low nitrogen (N) and phosphorus (P) availability. P deficiency in Kenyan soils is due to low occurrence of P containing minerals (Nyandat, 1981) and P fixation (Van der Eijk, 1997). Moreover, continuous cropping without supplying adequate nutrients is further contributing to an ongoing depletion of nutrients and low P contents in the soil (Smaling et al., 1997; Sanchez, 2002; FAO, 2004). The soils in the field experiments were selected to represent 4 different agro-ecological zones. Soils were classified as Ferric Alisols, Haplic Ferralsols and Ferric Acrisols (FAO-UNESCO, 1997). The total and available P contents in the 4 soils were low. From the field experiments, it became clear that maximum yields (which varied from 2.3 to 6.5 tonnes per ha, in dependence of maize variety and location) were obtained at application rates of 90 or 120 kg P_2O_5 per ha. The N application rate in all treatments was 80 kg N per ha.

Smaling and Janssen (1993) used a simple empirical model (QUEFTS) to evaluate 90 long term field experiments with maize in Kenya. The objective was to use the model for the development of fertilizer recommendations for N, P and K at the basis of simple soil analysis procedures. They succeeded in finding a good description of nutrient uptake and crop yield of maize based on the measurement of the following parameters:

- For N: organic N in the soil
- For P: total P, organic C and pH
- For K: exchangeable K and organic C in the soil

From this study it may be concluded that simulation models, like QUEFTS, may be used to extrapolate site specific results to other areas with similar agro ecological conditions in Kenya and neighboring countries and that N, P and K should always be considered together, because the supply of these major nutrients interact with each other.

In Kenya, several commercial soil analysis laboratories are active (e.g. www.soilcares.com), which supply fertilizer recommendations at the basis of the analysis of soil samples and knowledge that is derived from the field experiments which have been performed in the past. So, at the basis of the analysis of a soil sample, the expected lime and nutrient requirement for a specific crop that is grown on that soil will be supplied to a farmer or extension worker.

6.4 Possibilities for bioslurry to fulfill nutrient requirement of crops in Kenya

As has been described in the former subchapter, the nutrient requirement of maize in Kenya may strongly vary, in dependence of the environmental conditions. E.g. Smaling et al. (1992) showed that in some situations, maize only responded to P, in others only to N and only in some situations to a combination of N and P. So, in the ideal situation, only the most relevant nutrient(s) is/are supplied to the combination of crop and soil. However, in recent recommendations for maize in Kenya, in almost all situations a combination of animal manure (3-8 tons per hectare) and mineral fertilizer is recommended (NAAIAP, 2014).

Muchera-Muna et al. (2013) showed that the application of organic manures resulted in higher yields than the sole application of fertilizer N. They stated that the use of locally available manure is generally limited, because of low quality and quantity. Moreover, they indicated that maize grain yields over 3.5 tonnes per hectare were only obtained by combinations of farmyard manure and N and P fertilizers (Muchera-Muna et al., 2013). Titonell et al. (2008) also indicated that the combination of organic manure with mineral fertilizers may be beneficial in rehabilitating degraded soils.

Bioslurry may be considered as a combination of an organic and a mineral fertilizer, because it contains easily available nutrients and organically bound nutrients and organic matter. A characteristic of an organic fertilizer is that the ratio between nutrients is more or less fixed, unless certain nutrients are added to the fertilizer. This fixed ratio between N, P and K is a disadvantage, between it makes the fertilizer less flexible than desired. The fixed ratio between nutrients will not always be optimal for meeting the nutrient requirement of the crop, which may strongly differ between locations, as has been stated before. That is the reason that bioslurry should be used preferably in combination with mineral fertilizers, so that ratios between nutrients can be altered and adjusted to the requirement in a specific situation (crop, soil type and nutrient status of soil, weather/climate). Moreover the composition of bioslurry should be determined (see former subchapter)

This is illustrated by the following example:

We assume that the nutrient uptake and fertilizer recommendation for maize in a specific location in Kenya are as follows:

- Nutrient uptake: 50 kg N, 50 kg P (=114 kg P_2O_5) and 80 kg K (=96 kg K_2O) (Ademba et al., 2014)
- Fertilizer recommendation: 40 kg N and 60 kg P_2O_5 per ha.

We assume the following nutrient content of and nutrient supply by bioslurry:

- 5 kg N/ton, 2 kg P_2O_5/ton and 6 kg K_2O/ton (according to Table 5.1 in chapter 5).
- If 10 ton bioslurry is applied per ha, the nutrient supply is 50 kg N (we assume that about 40 kg N per ha is available), 20 kg P_2O_5 and 60 kg K_2O/ha.

So, the recommended N dose is met with the bioslurry application. However, the P-dose is only 20, while the recommendation is 60 kg P_2O_5. The difference (40 kg P_2O_5 per ha) should be applied in addition to the bioslurry with mineral fertilizer, e.g. single super phosphate (SSP). Moreover, in this example, the withdrawal of nutrients from the field is much higher (esp. of P and K) than the nutrient supply with bioslurry. This is undesirable, because it will lead to an exhaustion of nutrients from the soil at the long term. Therefore it is recommended to apply mineral fertilizers in addition to bioslurry to compensate for nutrient withdrawal by the crops, if that is higher than the nutrient supply with bioslurry.

7 Basic guidelines for user manual

Basic guidelines for a user manual for bioslurry consist of the following elements:

1. Guidelines for the reduction of nutrient losses;
2. Guidelines for the optimum application (optimum amount, way and time of application).

Re 1. Reduction of nutrient (esp. nitrogen) losses during the bioslurry production and application chain. The following guidelines are given:

- Take measures to reduce nutrient losses during anaerobic digestion:
  The anaerobic digestion should be performed in closed systems, by which the nutrient losses are low, normally spoken. No additional measures are required during this stage of bio-slurry production.
- Take measures to reduce nutrient losses during bio-slurry storage:
  - The storage capacity should be sufficient to prevent overflow;
  - N losses from bio-slurry by NH_3 volatilization should be minimized by closing or covering the storage;
  - Leaching of (nutrients from) bio-slurry should be preferably prevented by an impermeable barrier at the bottom of the storage.
- Take measures to reduce nutrient losses during bio-slurry handling (drying, composting, etc.):
  During the handling stage, it is of importance that all fractions of bioslurry are collected and no part (e.g. the liquid fraction) is disposed. Moreover, drying of untreated bioslurry or the solid fraction of bioslurry should be avoided. If bioslurry is composted, the bioslurry should be composted together with materials with high C/N-ratio (e.g. straw and/or woody material, such as prunings) to prevent N losses by NH_3 volatilization.
- Take measures to reduce nutrient losses during and after bio-slurry application:
  - if the consistency of the slurry is rather solid, dilute the slurry till it is rather fluid;
  - try to inject the slurry into the soil or cultivate the soil after application of the bioslurry;
  - apply the slurry during a period with little wind and low temperatures (e.g. in the morning or evening).

Re 2. Guidelines for the optimum application of bioslurry (amount, place and time)
For the determination of the optimum amount of bioslurry application in a specific situation, the following should be known:

- the nutrient requirement in that specific situation, characterized by the combination of crop, soil, region and season. For that reason it is advised to make use of fertilizer recommendations, which take into account nutrient requirement by the crop and nutrient supply by the soil. Therefore, soil samples should be taken, in which the nutrient availability should be determined. This can be performed by soil analysis laboratories that are active in Kenya (e.g. www.soilcares.com).
- The composition (nutrient content, dry matter, organic matter, pH) of the bioslurry. The following options are available for a determination: i) standard laboratory analysis, ii) estimation of the composition with quick tests and/or iii) by spectroscopy.
- The optimum amount of bioslurry application could be derived from the former steps. An outcome of this evaluation could be that mineral fertilizers are required in addition to the bioslurry.

With respect to the place of bioslurry application we recommend to apply it within the vicinity of the plant roots, in such a way that it is does not lead to salt stress and that it does not lead to nitrogen losses (see guidelines formulated above).

With respect to the timing of the bioslurry application, it is important that the nutrient supply from the bioslurry should be synchronized with the nutrient requirement of the crop. This means for example that the bioslurry should not be applied in a period without crop growth with high amounts of rainfall (because of leaching losses).

8 Evaluation and recommendations for future activities

8.1 Evaluation

From this study it has become clear that nutrients can get lost from the bio-slurry production during the following steps:

- anaerobic digestion, which may lead to relatively low N losses by NH_3 volatilization;
- handling, such as separation of slurry into a solid and liquid fraction, drying and/or composting of (the solid fraction of) bioslurry and/or disposal of the liquid fraction.
- storage, which may lead to high nutrient losses by overflow of bio-slurry, if the capacity of the storage is not large enough. Moreover, N losses may take place by NH_3 volatilization (up to 70% of total N), which may be esp. high if the storage is not covered.
- application: directly after the application of bioslurry, the risk for N losses by NH_3 volatilization is high and may be up to 50% of the total amount of NH_4-N in the slurry. The largest part of the NH_3 volatilization takes place within the first 24 hours after application.

Measures should be taken to prevent those losses.

Basic guidelines for a user manual for bioslurry consist of the following elements:

3. guidelines for the reduction of nutrient losses during the bioslurry production chain, i.e. during the anaerobic digestion, storage, handling and during and after application.
4. guidelines for the optimum application (optimum amount, way and time of application) consist of:
    - the determination of the nutrient requirement in a specific situation, characterized by the combination of crop, soil, region and season. For that reason it is advised to make use of fertilizer recommendations based on soil samples.
    - The composition (nutrient content, dry matter, organic matter, pH) of the bioslurry. The following options are available for a determination: i) standard laboratory analysis, ii) estimation of the composition with quick tests and/or iii) by spectroscopy.
    - The optimum amount of bioslurry application could be derived from the former steps. An outcome of this evaluation could be that mineral fertilizers are required in addition to the bioslurry.
    - With respect to the place of bioslurry application we recommend to apply it within the vicinity of the plant roots, in such a way that it is does not lead to salt stress and that it does not lead to nitrogen losses (see guidelines formulated above).
    - With respect to the timing of the bioslurry application, it is important that the nutrient supply from the bioslurry should be synchronized with the nutrient requirement of the crop. This means for example that the bioslurry should not be applied in a period without crop growth with high amounts of rainfall (because of leaching losses).

8.2 Recommendations

Our recommendations for future activities are as follows:

- Discussion with local partners about the provisional guidelines that have been formulated in the former chapter; based on those discussions, improvements of these provisional guidelines will be made. In 2015 we have already had some discussion with a bioslurry officer of the Tanzania Domestic Biogas Programme. The bioslurry officer confirmed that although farmers know that nitrogen may get lost from bioslurry, they are often drying or composting the bioslurry, because of advantages with respect to the storage and transport. After the application of bioslurry to the field, some farmers cover it with soil, thus preventing ammonia losses. However, the knowledge about the risks for nitrogen losses among farmers is till limited. This means that it appears to be useful to spread the user manual for bioslurry use among farmers.

- Evaluation about the possibilities of the implementation of the current guidelines in practice (in one or two regions, e.g. in Western / central Kenya). It should be explored what the eventual objections are.
- Further development of parts of the guidelines. We propose to work out the second part of the guidelines (for the determination of the optimum amount of bioslurry application, based on soil and bioslurry analyses) in close cooperation with a regional laboratory working on fertilizer recommendations based on rapid analysis methods (mainly spectroscopy). The laboratory (www.soilcares.com) already supplies fertilizer recommendations based on soil analysis with spectroscopical techniques, but does not offer bioslurry analyses at the basis of those new techniques yet. However, from the second part of 2015 onwards, the laboratory is able to start a stage for the development of a methodology for the measurement of the bioslurry composition based on a rapid technique (spectroscopy).
- Implementation of guidelines. Once the guidelines are fully operational, activities with the intention to implement them on practical farms could be started. It seems to be useful to implement those activities in existing programmes working on the dissemination of bioslurry knowledge to farmers. Examples of such programmes are the African Biogas Partnership Platform (ABPP), the Kenyan National Domestic Biogas Implementation Programme (KENDBIP), the Tanzanian Domestic Biogas Partnership Platform (TDBP).

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