Manure Management in the (Sub-)Tropics

Training Manual for Extension Workers

E. Teenstra, F. De Buisonjé, A. Ndambi, D. Pelster

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1 Wageningen UR Livestock Research

2 Food and Agriculture Organization of the United Nations (FAO)

3 International Livestock Research Institute (ILRI)

Cover photo: Asaah Ndambi – Trainees building a compost heap in Malawi.

Abstract (NL)
Het gebrek aan kennis van de waarde van dierlijke mest en van geïntegreerd mestmanagement bij overheden en samenleving heeft in een gezamenlijk actie geleid tot de samenstelling van een training handboek voor voorlichters over mestmanagement in de (sub-)tropen. Het handboek beschrijft de basisprincipes van geintegreerd mestmanagement voor de hele mestketen, vanaf de dierlijke uitscheiding tot en met de mestaanwending. Hoewel veel informatie is ontleend aan gematigde streken, richt het handboek zich vooral op de praktijk in de tropen en subtropen.

Abstract (UK)
Having identified a general lack of knowledge about the value of livestock manure and integrated manure management at multiple levels in government and society, a concerted action led to the compilation of a training manual for extension workers on manure management in the (sub-)tropics. Covering the whole manure chain, from animal excretion to the final application, the manual describes the basic principles of integrated manure management. Although much information originates from more temperate regions, the manual focusses on farm practices in the tropics and subtropics.

This activity was commissioned and funded by the Climate and Clean Air Coalition (CCAC).

Livestock Research Report 919

GLOBAL AGENDA FOR SUSTAINABLE LIVESTOCK

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

Manure Management in the (Sub-)Tropics

Training Manual for Extension Workers

Report 919

Wageningen UR Livestock Research

Rome/Wageningen, October 2015

LIVESTOCK RESEARCH WAGENINGEN UR

Food and Agriculture Organization of the United Nations

ILRI
INTERNATIONAL LIVESTOCK RESEARCH INSTITUTE

The Climate and Clean Air Coalition (CCAC) to reduce Short Lived Climate Pollutants (SLCPs) is a voluntary partnership of governments, intergovernmental organizations, representatives of the private sector, the environmental community, and other members of civil society that have joined forces to address the challenge of SLCPs. SLCPs have relatively short lifetime in the atmosphere - a few days to a few decades - and a warming influence on climate.

The main SLCPs are black carbon, methane and tropospheric ozone. After CO_2, they are the most important contributors to the human enhancement of the global greenhouse effect. These SLCPs are also dangerous air pollutants, with various detrimental impacts on human health, agriculture and ecosystems.

One of the CCAC's initiatives addresses SLCPs from agriculture. This initiative aims to reduce emissions of methane and black carbon from the agricultural sector to address climate change and to strengthen food security. The Livestock and Manure Management Component of the Agricultural Initiative is the initiator and funding body of the Manure Knowledge Kiosk.

(www.ccacoalition.org)

The Global Agenda for Sustainable Livestock (the Agenda) is a partnership of livestock sector stakeholders committed to the sustainable development of the sector.

Sustainability is a process of continuous practice change that addresses social, economic and environmental objectives simultaneously. To be sustainable, livestock sector growth needs to support the livelihoods of an estimated 1 billion people, contribute to enhancing economic and social well-being, protect public health through balanced diets and the reduction of health threats from livestock, and protect the natural resources.

The Agenda concurrently addresses three major areas: food security and global health; equity and poverty reduction; and resources and climate.

Stakeholders of the Agenda include the private sector, NGOs and social movements, government partners, research institutions, international agencies and foundations. The Agenda catalyzes policy dialogue into practice change. Within the action area of climate the Agenda hosts the Manure Knowledge Kiosk.

(www.livestockdialogue.org)

Preface

The Training Manual for Extension Workers on Manure Management in the (sub-)Tropics was compiled and first published in 2015 by the Livestock and Manure Management Component (LMMC) of the Agricultural Initiative of the Climate and Clean Air Coalition (CCAC) to reduce Short-Lived Climate Pollutants (SLCPs).

The primary objectives of the LMMC are to integrate manure management practices into livestock systems and improve existing practices to reduce SLCPs and other harmful emissions to the environment, capture methane as an energy source, and optimize nutrient utilization for crop production by managing and removing barriers to action with a view toward enhancing food security and sustainable development. The LMMC focusses on three regions: South and East Asia, Sub-Saharan Africa, and Central and South America.

One of the identified barriers for practice change is a lack of knowledge about the value of livestock manure and integrated manure management at multiple levels in government and society [24]. Ultimately livestock farmers are responsible for practice change in regard to manure management. They have to do it, but often lack the knowledge to make successful changes. Knowledge dissemination by government and non-government extension workers is the key to bridge this knowledge gap. Opportunities to change manure management practices at farm level through training of extension workers have been identified in all three focus regions. This eventually has initiated the concerted action of all project partners to compile this practical training manual.

Short-Lived Climate Pollutants (SLCPs)

SLCPs have relatively short lifetime in the atmosphere - a few days to a few decades - and a warming influence on climate. The main SLCPs are black carbon, methane (CH_4) and tropospheric ozone. After CO_2 they are the most important contributors to the human enhancement of the global greenhouse effect. These SLCPs are also dangerous air pollutants, with various detrimental impacts on human health, agriculture and ecosystems.

Worldwide livestock accounts for 33 % of the anthropogenic CH_4 emissions of which 90 % come from enteric fermentation processes in the animal (mainly ruminants) and 10 % from manure [CCAC]. The latter may look insignificant compared to the total percentage; however, reducing CH_4 emission from manure by improving manure management is easy compared to a reduction of the emissions from enteric fermentation since this is a natural body function of ruminants and will involve many factors (e.g. the animal species, feeding practices, feed quality and even cropping patterns).

Improving knowledge about the value of manure should prevent situations like this where manure flows freely out of a cow shed.

This Training Manual aims to enhance the knowledge of extension workers, which enables them to assist livestock farmers with relevant and to local farming conditions adapted knowledge to improve their manure management. Instead of presenting carved-in-stone extension messages, the manual puts more emphasis on the guiding principles of manure management than on the details. The manual is also by no means meant to be a scientific report. There is undoubtedly a lot more information available than reflected in the current manual. A manure management customized library function is available at www.manurekiosk.org.

Notably this manual is about manure management and not about the technical issues of farm equipment and installations. Although anaerobic digestion to harvest biogas from animal manure is highly promoted and already being used in many parts of the world, the manual does not go into technical detail about the installations, but emphasizes the use of the effluent (the digestate or bioslurry), since this is still a valuable organic fertilizer. More information on biogas can be found at several web portals e.g. the Global Methane Initiative and the European Biogas Initiative: EU-Agrobiogas.

Dealing with the whole manure chain, the training manual initially covers many possible situations in the tropics and sub-tropics. However, integrated manure management is always site specific. Therefore the trainers are advised to only use the information relevant to local circumstances; e.g. smallholder farmers have other knowledge needs than farm managers of large industrial livestock enterprises.

Acknowledgements

Compilation of the manual has been a concerted action by experts from Wageningen UR Livestock Research, the Food and Agriculture Organization of the United Nations (FAO), and the International Livestock Research Institute (ILRI); with support from the Tropical Agricultural Research and Higher Education Center (CATIE), and Stockholm Environment Institute (SEI) plus their local partner SNV Netherlands Development Organization.

Information sources are listed at the end and referred to in the manual using numbers between square brackets.

The LMMC partners are grateful for the expert review of the manual by Dave Chadwick, Professor of Sustainable Land Use Systems, Bangor University, UK; Richard R. Stowell, Associate Professor and Extension Specialist – Animal Environment, University of Nebraska-Lincoln, USA; Tom Misselbrook, Principal Research Scientist, Sustainable Soils and Grassland Systems, Rothamsted Research, North Wyke, UK; and Theun Vellinga, Senior Research Scientist Animal Production Systems and Climate Change, Wageningen UR Livestock Research, Wageningen , The Netherlands.

Unless mentioned otherwise, all illustrations and photographs are by Edsger Teenstra.

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Abbreviations

In alphabetical order

AD	:	Anaerobic Digestion
CCAC	:	Climate and Clean Air Coalition to reduce Short-Lived Climate Pollutants (SLCPs).
CH_4	:	Methane (Greenhouse Gas, 28 times more powerful than CO_2)
CP	:	Crude Protein
DM	:	Dry Matter
FM	:	Fresh Matter
FYM	:	Farm-yard manure
IMM	:	Integrated Manure Management
K_2O	:	Potash ($K_2O = K \times 1.2$ $K = K_2O / 1.2$)
LMMC	:	Livestock and Manure Management Component
N_2O	:	Nitrous oxide (Greenhouse Gas, 265 times more powerful than CO_2)
OM	:	Organic Matter
P_2O_5	:	Phosphate ($P_2O_5 = P \times 2.29$ $P = P_2O_5 / 2.29$)
SLCP	:	Short-Lived Climate Pollutant (as is CH_4 from livestock)

Glossary

Anaerobic Digestion	:	decomposition of *biomass* in an oxygen-free (anaerobic) environment.
Biogas	:	volatile product of *anaerobic digestion* containing mainly methane (CH_4), carbon dioxide (CO_2) and some hydrogen sulphide (H_2S).
Biomass	:	mass of vegetal and animal material, in this manual only used in the context of materials with a vegetal origin.
Bioslurry	:	same as *digestate*.
Digestate	:	effluent of *anaerobic digestion*.
Digester	:	air tight vessel for *anaerobic digestion* of *biomass*.
Dung	:	excretion of mainly undigested feed and fodder from the digestive track of livestock, also known as feces.
Mineralization	:	decomposition of organic matter by microorganisms in which organically bound nutrients are transformed into mineral nutrients.
Manure	:	mixture of *dung* with possibly *urine*, bedding material and flushing water.
Short-Lived Climate Pollutant	:	air pollutant with a relatively short lifetime in the atmosphere, a warming influence on climate, and various detrimental impacts on human health, agriculture and ecosystems. Main SLCPs are black carbon and the greenhouse gases methane (CH_4) and tropospheric ozone (O_3). (Note: N_2O and CO_2 are Long-Lived Climate Pollutants)
Urine	:	liquid excretion by the kidneys consisting of diluted metabolic waste and surplus substances such as nitrogen.

Summary

The Training Manual on Manure Management in the (sub-)Tropics is targeted at Extension Workers (in the agricultural field) to increase their knowledge and experiences for further dissemination to farmers. The content follows the consecutive steps of the manure chain, from the animals' excretion up to the final use as organic fertilizer. Each chapter opens with text box stating what knowledge farmers need to have in order to improve their manure management practice.

Integrated Manure Management

WHAT FARMERS NEED TO KNOW

- *Manure is a valuable resource of energy, organic fertilizer and soil improver that should not be wasted.*
- *Bio-digestion of manure produces clean and cheap energy.*
- *Applying manure to soils saves on purchase of synthetic fertilizer, increases crop yield and saves water.*

Integrated Manure Management (IMM) is the optimal, site-specific handling of livestock manure from collection, through treatment and storage up to application to crops (and aquaculture).
Key facts are that (1) the housing system determines the major manure characteristics and (2) immediately after excretion nutrients may start getting lost. The challenge of IMM is to prevent these nutrient losses in the manure chain as much as practically possible.

Initially, dung and urine are the substances excreted by the animals. As soon as dung is mixed with other substances like urine, water, or bedding materials, it is called manure. Based on the dry matter content, manure distinguishes several types (see Figure A).

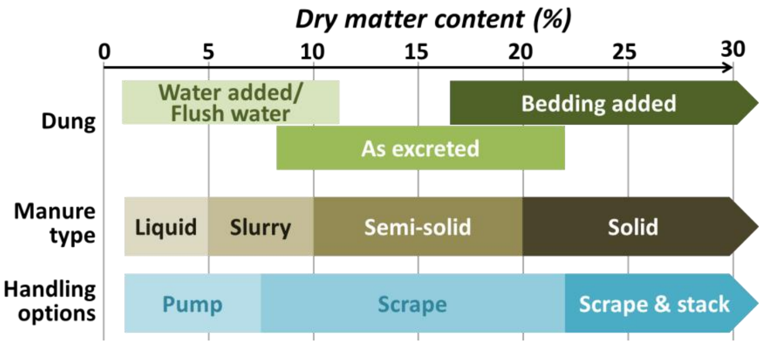

Figure A. Main manure types according to their dry matter content [8].

Manure plays an essential role in the nutrient cycle where crops grow on land to feed livestock, which in return feeds the land with their manure. Recycling the (macro and micro) nutrients in manure reduces the need for additional fertilizer purchase. In general, adding manure to soils enhances soil fertility and soil health that leads to increased agricultural productivity, improved soil structure and biodiversity. Although the benefits of using organic fertilizer are overall quite clear, for most common tropical crops it proves to be very difficult to assign a value to these benefits. In spite of the many trials using organic fertilizers, it is impossible to compare their outcomes in terms of yield effects and effects on income. Major differences are caused by differences in: applied manure types and doses, nutrient contents, used crops (and varieties), agro-ecological circumstances, combinations with inorganic fertilizers, soil conditions, etc.

Animal Excretion

WHAT FARMERS NEED TO KNOW

- *A higher nutrient intake, results in a higher nutrient content of dung and urine.*
- *Urine contains mineral nitrogen and potassium.*

Dung is undigested feed components, including nutrients, as well as endogenous digestive losses. Urine contains inevitable losses, waste products of metabolic processes and surplus nutrients. The amount of dung and urine produced by animals is very variable due to differences in feed and water intake, which are strongly related to body weight and production intensity.

Nitrogen in animal manures is present in two forms: organic and (inorganic) ammoniacal nitrogen. Most organic N is contained in the organic matter, while the ammoniacal N is present as either ammonium (NH_4^+) or as free ammonia (NH_3). Exposed to open air, NH_4^+ is transformed into gaseous NH_3 that is usually lost into the atmosphere.

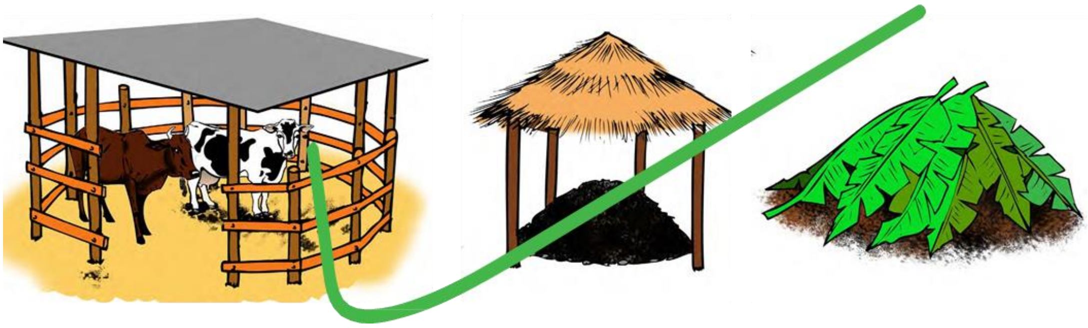

Figure B. Covering manure prevents nitrogen loss trough leaching, run-off and volatilization. (source: ILRI)

Housing and Manure Collection

WHAT FARMERS NEED TO KNOW

- *Animal housing should allow the collection of all dung and urine and prevent losses.*
- *Solid manure should be stored on a waterproof floor and with a cover against rain.*
- *Urine should be collected because it is a valuable source of nitrogen and potassium fertilizer.*

Most important to know is that the housing system determines the major manure characteristics. Dung and urine of confined animals can be easily collected. In kraal systems, animals have some confinement, which allows collection of manure, but when kept on bare soil, urine cannot be collected and the manure is subject to higher nutrient losses. Flooring facilitates collection of both dung and urine. Similarly, manure stored in roofed houses is less exposed to nitrogen losses through volatilization. Roofing also prevents run-off and seepage losses of nutrients due to rain (Figure B). This partially overlaps with the next chapter on storage. Because urine is liquid it can easily get lost. Collecting urine with the dung to form slurry is the easiest way, but often not very feasible on smallholder farms. Urine can also be captured through the use of bedding materials.

Manure Storage

WHAT FARMERS NEED TO KNOW

- *Proper storage preserves crop nutrients until the time of application.*
- *Storage roofing prevents runoff of nutrients to the soil and water.*
- *Storage flooring prevents leaching of nutrients into the soil and water.*
- *Air-tight storage covering prevents nutrients from volatilization to the air.*

Manure storage is necessary to bridge the gap between the moment of excretion and the optimal moment of application on cropland. This is also the period in which nutrients are very susceptible for losses to the environment. These losses can be reduced by limiting the contact surface between manure and air by stacking and compressing the heap and by protecting the manure against the influence from wind, water and sunlight. The nitrogen amount in the manure tends to decrease over time, because NH_3, N_2 or N_2O are emitted or because soluble N is leached by rainwater. The P_2O_5 and K_2O can also be lost by leaching from rainfall, further reducing the value of the manure.

The major emission from prolonged storage of slurry in lagoons, deep pits or silos will be CH_4. This emission can be reduced by anaerobic digestion of the fresh slurry. Proper manure storage plays a key role in preventing environmental pollution and other nuisances like bad odor and flies.

Anaerobic Digestion

WHAT FARMERS NEED TO KNOW

- *Biogas substitutes for fossil fuel and biomass fuel.*
- *A biodigester needs to be fed with fresh manure every day of the year.*
- *Digestion of manure does not change the nutrient content of manure; bioslurry is still a valuable fertilizer.*

Production of biogas through anaerobic digestion of organic material e.g. manure, is a relatively simple technology that can be implemented at industrial, village and farm household scales. Anaerobic digestion (AD) is a biochemical process during which complex organic matter is decomposed in absence of oxygen by various types of anaerobic microorganisms. Although biogas can be generated by a wide range of organic material, cattle dung is best suited for small farm installations. Coproducts of biogas are the bioslurry and the sludge on the bottom of the digester. If done properly, no nutrients will be lost during AD.

Gas yields differ depending on volumes, type of manure and digester technology. Manure from pigs and poultry yields more gas than from cows. The required digester size is determined by the daily quantity of feedstock added and the time needed for the full digestion of the feedstock inside the digester. For simple domestic biogas installations, this period varies from 45 days in warm areas to 55 days in temperate areas.

Manure Treatment

WHAT FARMERS NEED TO KNOW

- *If mechanized application is not possible, composting is the best way to store manure and ease its transport and field application.*
- *Also (bio-)slurry can be composted.*
- *Drying (bio-)slurry loses 50 % of the total nitrogen.*

Manure may be treated for several reasons, e.g. to reduce the volume, to improve the applicability, to prevent losses during storage, and perhaps to increase the value.

Air drying is an easy method to reduce the volume of liquid manures like slurry and bioslurry. A major disadvantage of air drying is that practically all mineral N is lost through NH_3 volatilization.

Physical separation is a mechanical treatment mostly applied to slurries to separate the slurry into a relatively N-rich liquid fraction and a relatively P_2O_5-rich solid fraction.

Composting is an attractive proposition for turning on-farm organic waste materials into a farm resource and is suitable in all farm situations, large or small and with solid and liquid manure types. However, compost production is labor intensive and demands regular attention. The two most common methods are (1) the heap or pile method, suitable for large-scale processing and for small-scale operations in areas with higher rainfall, and (2) the pit method, suitable for small-scale processing in areas with low rainfall and a long dry season <u>and</u> for composting of liquid manures.

Application of Organic Fertilizers

WHAT FARMERS NEED TO KNOW

- *Manure substitutes for (expensive) synthetic fertilizers.*
- *Manure must only be applied at the time the crops need the nutrients.*
- *The application dose depends on the crop requirements and soil fertility, and on the available amount of nutrients in the manure.*
- *To know the nutrient content, soil and manure need to be analyzed for N, P and K.*
- *Application of synthetic fertilizers is complementary to the use of manure.*
- *(bio-)Slurry should not be applied to fruits and vegetables grown for fresh consumption.*

The basic idea of fertilization is to keep soils healthy and fertile. In practice this implies always to replenish the amount of nutrients which is harvested with crops. It is impossible to give an amount for each crop, since this depends on many factors. It is an important role for research and extension to provide the appropriate figures about the harvested amount of nutrients in locally common crops.

The desired application rate is calculated from crop demand (based on the expected amount of harvested nutrients) minus soil supply and a possible correction for either over-fertilized soils or mined soils (based on chemical soil analysis). This results in the initial required nutrient supplementation. The required supplementation divided by the crop available nutrient content per unit fresh matter (based on chemical analysis and the working coefficient) results in the required amount to be applied. When manure is available and since this is cheaper than synthetic fertilizer, it is logical to start with the manure. Only if the required manure quantity is not available or not enough, a supplementation with synthetic fertilizer is appropriate. The required amount can be calculated in the same way.

Because the nutrient content of manure, particularly nitrogen, can change during storage, sampling and analysis should be performed as close to the time of application as possible.

The method of application depends on the composition of the manure product, type of crop, soil type, and farm scale. Manure should not be applied on the field when there is no nutrient uptake by the crop.

All application methods should aim to prevent nutrients (mostly N) from getting lost prior to uptake by crops. To minimize open air exposure, manure should be incorporated into the soil (e.g. by harrowing) during or immediately after spreading.

Information on the crop response to using organic fertilizers is very diverse. Most studies, in which correct methodologies were used, did not show significant differences in yield between the use of bioslurry and farmyard manure.

The use of organic manure for fish pond fertilization has become very important, basically to increase the biological productivity of fish ponds. All studies show positive results when done correctly, as slurry considerably increases the population of phyto- and zooplankton, thereby increasing the amount of fish feed in the ponds. Overall, 50 kg of manure produces 1 kg of fish.

Closing Remark

Knowing that in practice there still exist many barriers and bottlenecks hindering the optimal use of livestock manure, it is good to realize that it is better to apply it in a suboptimal way than not applying it at all and having manure be only a pollutant!

Table of Contents

1 Integrated Manure Management

WHAT FARMERS NEED TO KNOW

- Manure is a valuable resource of energy, organic fertilizer and soil improver that should not be wasted.
- Bio-digestion of manure produces clean and cheap energy.
- Applying manure to soils saves on purchase of synthetic fertilizer, increases crop yield and saves water.

Integrated Manure Management depends on **two basic principles:**

1. **The housing system determines the major manure characteristics.**
2. **Immediately after excretion nutrients may get lost throughout the whole manure chain up to the moment of crop uptake after application.**

Definition

Integrated Manure Management (IMM) is the optimal, site-specific handling of livestock manure from collection, through treatment and storage up to application to crops (and aquaculture).

Optimal refers to the key aim and challenge of **preventing nutrient losses in the manure chain as much as practically possible** under the site-specific circumstances. Site-specific circumstances refer to the agro-ecological and socio-economic situation along the manure chain (see Figure 2) which also includes the possibilities for investments.

At this point it is appropriate to use a unified terminology. Initially dung and urine are the substances excreted by the animals.

The consistency of dung may differ greatly mainly because of differences in the animals' diet; more on that subject in the next chapter. As soon as dung is mixed with other substances like urine, water, or bedding materials, it is called manure.

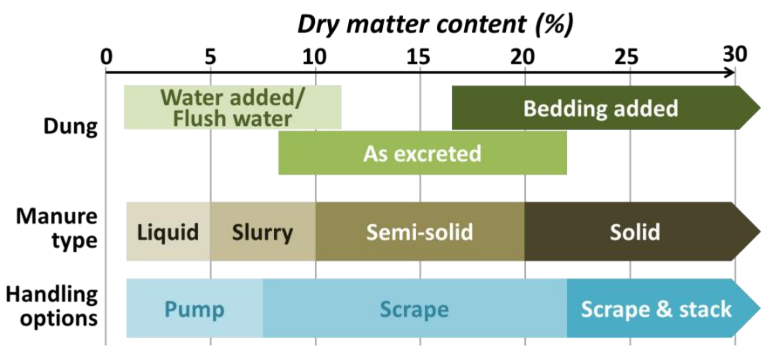

Figure 1. Main manure types according to their dry matter content [8].

Several manure types can be distinguished (Figure 1). The most distinguishing factor is water content. Where dung and urine are collected together the final manure type is most often slurry. Dung mixed with feed leftovers and or bedding materials (often soaked by urine) results in a solid and stackable farm-yard manure.

This manual only refers to manure management when the possibility exists of collecting dung and urine. In practice this implies that the animals are fully or partially confined. Since dung and urine excreted outside confinement e.g. during grazing or scavenging are uncollectable these fall beyond the scope of this manual.

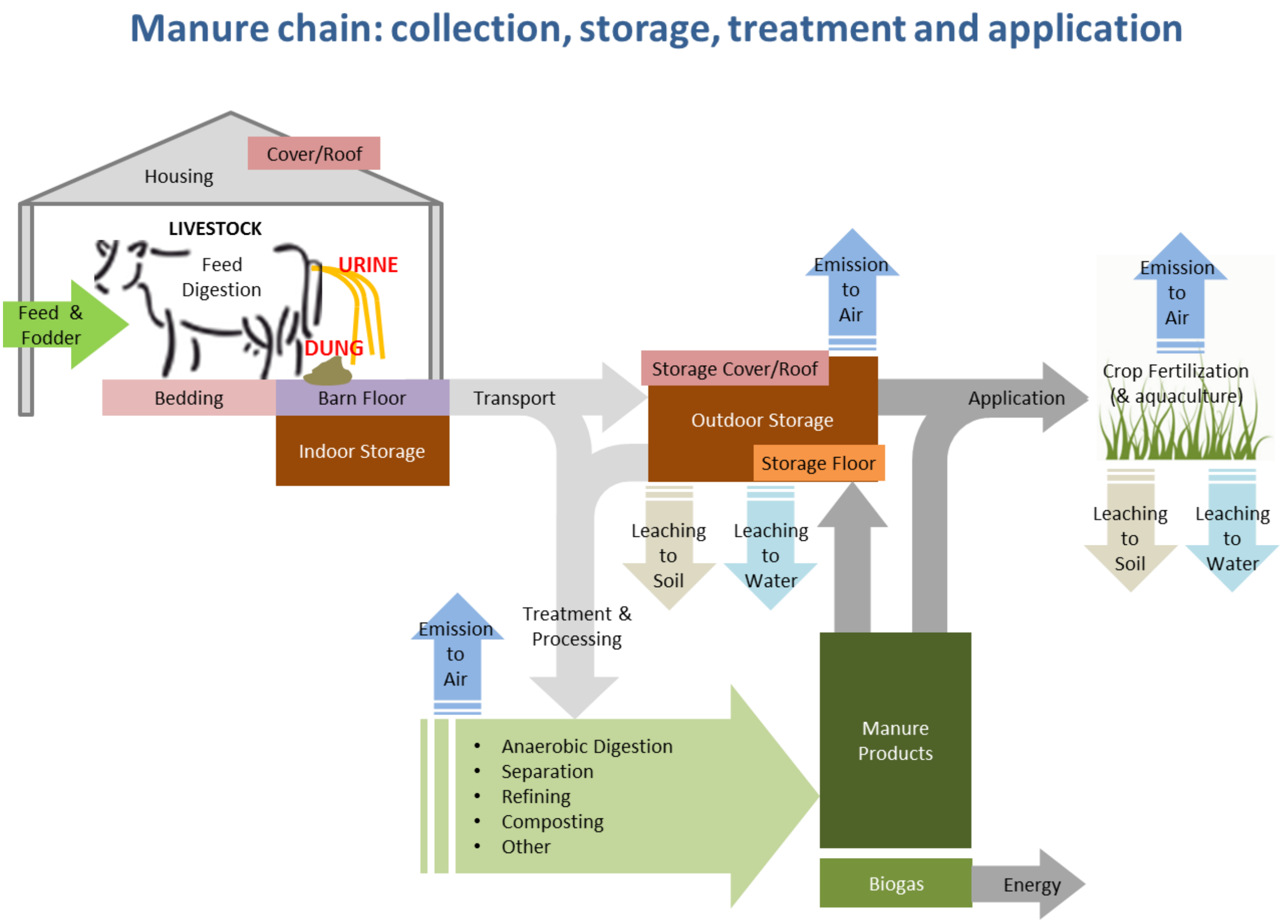

Figure 2. Schematic overview of the manure chain from collection to application. Outdoor Storage and Treatment & Processing can also sometimes be combined. Note: the dairy cow symbolizes all livestock.

Livestock in Figure 2 covers ruminants (cattle, buffalo, goats and sheep) as well as monogastrics (pigs and poultry) in partial or total confinement. Following the definition, well-performed IMM always results in the highest fertilizing value of manure, thus making manure a valuable resource for crop growth and aquaculture.

1.1 Nutrient cycle

Manure plays an essential role in the nutrient cycle (Figure 3) where crops grow on land (soil) to feed livestock, which in return feed the land with their manure. The challenge is to recycle manure nutrients into the feed chain instead of losing them to the environment. Recycling these (macro and micro) nutrients enhances crop production and reduces the need for additional synthetic fertilizer purchase.

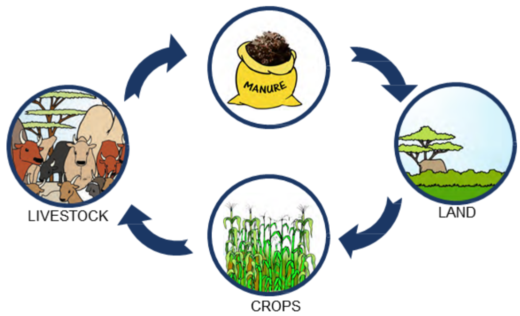

Figure 3. Nutrient cycle of crop-livestock systems. (source: ILRI)

Reduce losses

According to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, total nitrogen losses from manure range from 10 to almost 100 %, depending on animal species and manure management system. Based on 2005 figures and taking into account all factors affecting N losses, the overall nitrogen loss from manure in the world is ca. 40 %. With the assumption that all manure is used for application reducing these losses to e.g. 30 % would save ca. 22 Mega tons of nitrogen! This amount is comparable to almost a quarter of the world's total synthetic fertilizer use in the same period. Especially for Sub-Saharan Africa where synthetic fertilizer use is very low (less than 2 kg per ha), the efficiency gain (Figure 4) would be about twofold the average use of synthetic fertilizer.

Figure 4. Available N from manure per ha grassland and arable crops and the N gain (dark topping) if losses are reduced from 40 to 30 %.

Synthetic fertilizer replacement

As often stated, manure has a notable synthetic fertilizer replacement value (SFRV). In other words, the nutrients in manure can substitute for nutrients in synthetic fertilizers as shown in Figure 5. In situation "a" 25 % of the Synthetic Fertilizer is replaced by organic fertilizers, whereas in situation "b" 75 % is replaced. But the SFRV is only relevant in situations with sufficient availability <u>and</u> resources to purchase synthetic fertilizers!

In many regions this is not the case, making livestock manure the only available crop fertilizer. Reducing nutrient losses in the manure chain, thus applying more nutrients to crops than before, will have an immediate positive effect on crop production; at least when other growing factors like water are not limiting crop growth. This is also visible in Figure 4.

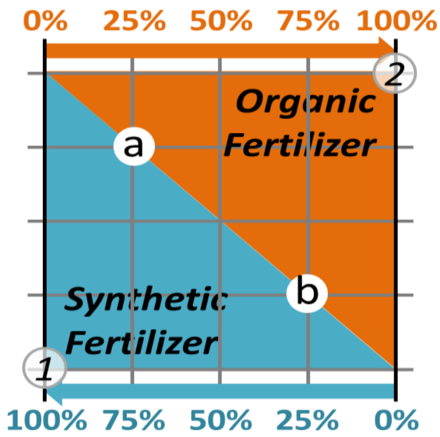

Figure 5. Organic fertilizer replacing synthetic fertilizers (read direction: bottom to up).

In a worst-case scenario, a lack of purchasing power also indicates that these farm families operate on a subsistence level with often low inputs and, as a consequence, also low production of crops and livestock. When manure is not properly used this will end up in a downward spiral threatening the family's food security and livelihood. Without the possibility to adapt to future climate change, this situation will definitely worsen.

1.2 Important resource

Manure is an important low-cost source of crop nutrients in mixed crop-livestock systems.

In general, adding manure proving nutrients and organic matter to soils enhances soil fertility and soil health that leads to increased agricultural productivity, improved soil structure and biodiversity. Also, improved soil structure will increase water-holding capacity and erosion control along with increasing drainage and permeability and reducing soil acidity.

Improving soil health, drought resilience and nutrient levels through the use of livestock manure from a sound manure management system will immediately enhance crop production. Subsequently, this **improves both the quality and quantity of food and feed leading to a better nutrient status of the family.** Eventually the situation may arise where food security is not an issue anymore and in which even a product surplus may occur to be sold on local markets.

1.3 Benefits of Integrated Manure Management

Overall manure is a source of **energy, organic fertilizer and soil improver**. The benefits of using manure as a resource are multiple, e.g.:

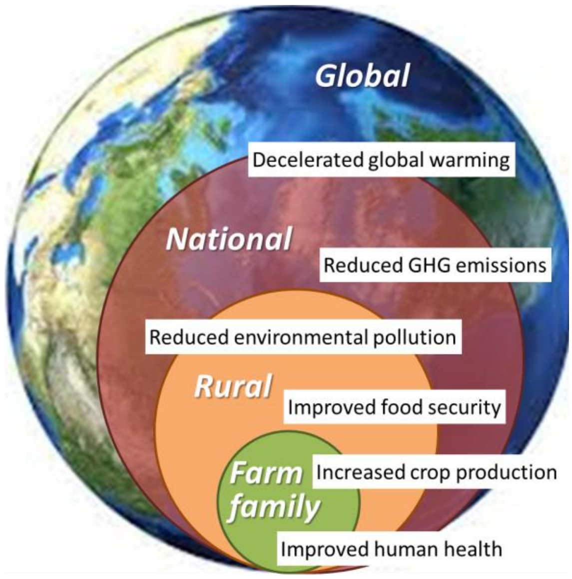

Figure 6. Beneficiaries of integrated manure management.

- increasing nutrient efficiency
  ➔ reduces nutrient losses;
- less nutrient losses
  ➔ higher manure nutrient value;
- less nutrient losses
  ➔ reduces environmental pollution;
- less environmental pressure
  ➔ reduces public health threats;
- certain manure treatments reduce (zoonotic) pathogens and parasites;
- certain manure treatments reduce the germination power of or even kill weed seeds;
- harvesting methane (biogas)
  ➔ saves fossil fuel (money) and or biomass fuel (money/effort);
- with biogas no need for biomass collection ➔ saves time (to spend on other income generating activities);
- cooking with clean biogas ➔ prevents inhalation of smoke and particulate matter;
- less harmful inhalations ➔ improve human health;
- harvesting methane ➔ reduces methane emission to the air;
- less methane emission ➔ slows down global warming;
- applying manure to soil ➔ increases soil organic matter content;
- increased organic matter content ➔ enhances soil health;
- increased organic matter content ➔ increases the soils water-holding capacity;
- better water-holding capacity ➔ improves resilience to climate change;
- increased water-holding capacity ➔ preserves water for crop growth;
- applying manure to soil ➔ improves crop nutrient supply;
- improved crop nutrient supply ➔ enhances crop growth and yield;
- optimal manure nutrient value ➔ reduces need for synthetic (inorganic) fertilizer;
- reduced use of synthetic N fertilizer ➔ saves money and the energy to produce and transport it;
- enhanced crop growth and yield ➔ improves food security;
- enhanced crop growth and yield ➔ improves feed quality;
- better feed quality ➔ improves livestock production;
- enhanced crop and livestock production ➔ increases farm income;
- better income, more food, improved health ➔ improves livelihood.

1.4 Costs of Integrated Manure Management

Unfortunately not all benefits come free of charge. Harvesting CH_4 implies investing in a digester. Also better collection to prevent immediate losses and unwanted discharge may come with a cost e.g. for flooring and or roofing. Making optimal use of the manure products for crop fertilization may also demand investments in storage to bridge the gap between the moment of collection and the right moment of application to crops.

Investing in improving manure management may not always immediately pay off on the short term (e.g. better crop yields), but it will definitely pay off on the long term when you take into account the real added value of soil resilience to climate change, and improved food security and human health.

Labor

The proper handling of manure also needs labor, and depending on the management measures, sometimes a lot of labor, e.g. collecting the manure, building a compost heap, maintaining it, and finally transporting and applying the compost to the field takes a lot of effort and time. This is one of the main reasons why the use of synthetic fertilizer has become so popular. The shortage of labor and time is also an important barrier for many farmers and farming households to improve their current manure management [24].

1.5 Valuing manure use

Although the benefits of using organic fertilizer are overall quite clear, it proves to be very difficult to value these benefits for the most common tropical crops. In spite of the many trials using organic fertilizers, especially bioslurry, the lack of a protocol to standardize these trials makes it impossible to compare their outcomes in terms of yield effects and effects on income. Major differences are caused by differences in: applied types and doses, nutrient contents, used crops (and crop varieties), agro-ecological circumstances, combinations with inorganic fertilizers, soil conditions etc. Chapter 7 presents some examples.

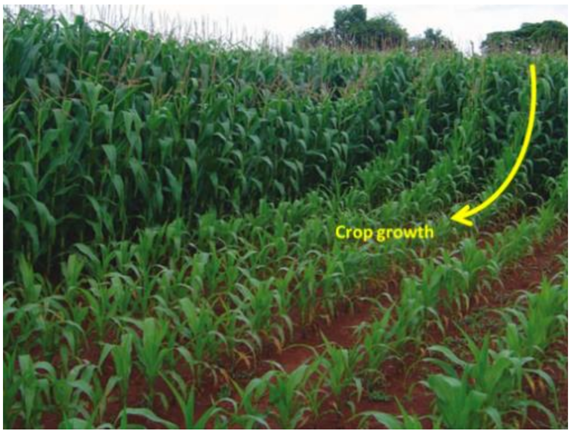

Figure 7. Effect of bad P_2O_5 supply (foreground) on crop development of forage maize.

1.6 Detrimental losses

As stated, Integrated Manure Management (IMM) is the optimal, site-specific handling of livestock manure throughout the whole manure chain, in which the key aim is preventing nutrient losses, and thus saving as much nutrients as possible to fertilize crops. Besides the monetary loss, nutrient losses from livestock manure can have detrimental effects on the environment at local, national and global scale. Losses can be emissions to the air, like CH_4, N_2O and NH_3; or to water sources by leaching of e.g. NO_3^- and P_2O_5 through the soil and by run-off (including intended discharge).

- CH_4 (methane) : combustible greenhouse gas, 28[1] times more powerful than CO_2; produced from the decaying organic matter in manure stored under oxygen-free conditions.
- N_2O (nitrous oxide) : greenhouse gas, 265[1] times more powerful than CO_2; intermediate product during (1) the nitrification of NH_4^+ into NO_3^-; and (2) during the denitrification of NO_3^- in manure applied to soils low in oxygen (e.g. waterlogged).
- NH_3 (ammonia) : aggressive and acidifying gas; product from urea degradation in manure (urine); causing respiratory problems in humans and animals and acidification of soils when deposited.
- NO_3^- (nitrate) : formed in the soil by nitrification of NH_4^+ / NH_3 after manure application, water-soluble ion prone to leaching; high concentrations in potable water may lead to nitrite poisoning (NO_2^-) causing an oxygen deficit in the blood of humans and animals.
- P_2O_5 (phosphate) : from superficial run-off of manure and/or from leaching of the water-soluble form, causing eutrophication of open waters (dense growth of algae and death of fish from subsequent lack of oxygen).

[1] Source: IPCC: Climate Change 2013, the Physical Science Basis (table 8.7, page 714)

2 Animal Excretion

WHAT FARMERS NEED TO KNOW

- A higher nutrient intake, results in a higher nutrient content of dung and urine.
- Urine contains mineral nitrogen and potassium.

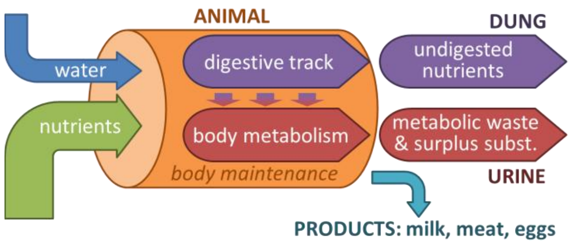

Figure 8. Simplified input and output flows of livestock.

Dung is undigested feed components, including many nutrients, as well as endogenous losses. Urine contains inevitable losses, waste products of metabolic processes and surplus nutrients. The quantity of nutrients excreted depends on the nutrient intake level, the efficiency with which the nutrients are utilized by the animal for growth (meat), maintenance and other functions (e.g. milk, eggs) and the amount of normal metabolic losses (endogenous) (Figure 8).

Depending on the animal species, their feed basket and production level, the N and P efficiency (amount of nutrients in livestock products as a percentage of the total nutrient intake) varies from about 5 to 30 %; whereas 5 % is more related to ruminants in low productive systems and 30 % refers to ruminants and monogastrics in high productive systems. This implies that almost 70 % or more of the fed nutrients end up in the excretions. Besides the primary plant nutrients N, P_2O_5 and K_2O, dung and urine also contain secondary nutrients such as magnesium, calcium, sulphur and trace elements like zinc, copper, molybdenum, manganese, cobalt and selenium. Animals fed rich diets with high crude protein content typically excrete more nitrogen than animals fed low quality (less protein rich) diets.

Intensive systems

Table 1 gives an example of slurry compositions from intensive livestock systems with fattening pigs on compound feed and cattle that received concentrate as a supplement to roughage. In addition Table 2 shows the annual slurry production of cattle and pigs and the annual manure production of broiler and layer chickens again in intensive livestock systems.

Animal Nutrition versus Crop Fertilization

As a rule in animal nutrition, demand and supply are projected as single elements like P (phosphorous) and K (potassium) whereas in crops demand and supply are always projected as chemical compounds like P_2O_5 (phosphate) and K_2O (potash). To switch between those two:

$P_2O_5 = P \times 2.29$ $(P = P_2O_5 / 2.29)$

$K_2O = K \times 1.2$ $(K = K_2O / 1.2)$

Table 1. Composition of fattening pig slurry and cattle slurry from intensive livestock systems (mainly in temperate regions). [12]

	Fattening pig slurry (dung + urine)	Cattle slurry (dung + urine)
Component	Concentration in g/kg FM	Concentration in g/kg FM
Dry Matter	100.0	96.0
Organic dry matter	66.0	67.3
Inorganic dry matter (Ash)	34.0	27.6
N-Total	7.2	4.9
N-NH_4^+	4.2	2.4
N-organic	3.0	2.5
P_2O_5	4.2	1.7
K_2O	6.8	5.9
CaO (lime = Ca [Calcium] x 1.4)	4.0	3.1
MgO	1.8	1.4

Table 2. Estimated excretion of fresh manure by livestock species in intensive production systems. [12]

Animal species	Slurry (dung + urine) production per animal per year (kg)	Solid manure tons per year
Dairy cow 8,000 kg milk/year	25,000	4.4 – 16
Veal (per animal place[1])	11,000	4 – 15
Fattening pig (per animal place[1])	1,500	0.8 – 1.6
Sow	4,000	2.7 – 3.7
Broiler (per animal place[1])		36 kg
Layer		50 kg

1 in intensive production systems an animal place is approx. 2.5 rounds of veal per year, 3 rounds of fattening pigs per year and 7 rounds of broilers per year.

Extensive systems

The amount of dung and urine produced by animals is very variable due to differences in feed and water intake, which in turn are strongly related to body weight and production intensity; i.e. with half the milk production level of Table 2, the excretion of a dairy cow would approximately be 10 to 15 tons per year. The DM content of dung is very variable, even within species (Figure 9).

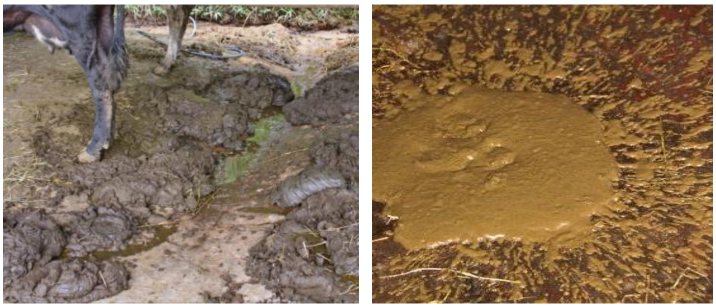

Figure 9. Semi-solid and very liquid dairy cattle dung.

The excretion of solid dung of cattle (dairy and beef) in more extensive tropical systems is estimated to vary from 5 to 8 tons per year. Table 3 gives some examples of excretions under extensive tropical conditions with e.g. cows weighing around 250 to 400 kg. Note: the excretion in intensive livestock systems under tropical conditions will not differ from that in temperate regions.

Table 3. Amounts of animal excretions under extensive tropical conditions per day. [5]

	Amount of excretions as percentage of average body weight		Amount of fresh dung (kg/day)
	Dung	Urine	
Cow	5	4 – 5	15 – 20
Buffalo	5	4 – 5	18 – 25
Pig	2	3	1.2 – 4.0
Goat/sheep	3	1 – 1.5	0.9 – 3.0
Chicken	4.5		0.02 – 0.15

Nitrogen

Nitrogen in animal manures is present in two forms: organic nitrogen and inorganic nitrogen. Most organic nitrogen is in the form of proteins and nucleic acids, while the inorganic nitrogen is present as either ammonium, NH_4^+, or as free ammonia, NH_3. Poultry manure also contains the inorganic uric acid. Urea excreted in urine is converted by enzymes into ammonium/ammonia (NH_4^+/NH_3) within hours after excretion. Organic nitrogen in dung takes much longer to mineralize to NH_4^+/NH_3. Uric acid in poultry dung is converted into NH_4^+/NH_3 within days after excretion. When conditions are favorable, NH_4^+ is transformed into gaseous NH_3 that is usually lost to the atmosphere.

3 Housing and Manure Collection

WHAT FARMERS NEED TO KNOW

- Animal housing should allow the collection of all dung and urine and prevent losses.
- Solid manure must be stored on a waterproof floor and with a cover against rain.
- Urine should be collected because it is a valuable nitrogen and potassium fertilizer.

The housing system determines the major manure characteristics. Dry manure, solid manure, farm-yard manure, slurry and liquid manure are manure types that can be found throughout different livestock systems. As stated in Chapter 1, as soon as dung is mixed with other substances like urine, water, or bedding materials, it is called manure. Whether dung gets mixed with other substances highly depends on the housing system (Figure 10). Table 4 presents the major manure types from different housing and management systems for cattle, pigs and poultry and indicates the suitability for different manure applications.

Figure 10. Fattening pigs in confinement with flush area.

Table 4. Relationship between housing system and manure type, with indications of the suitability of different manure types for different treatments[1] and applications.

Housing systems	Collection & Additions	Manure type	Most suitable for:
For cattle:			
Free range + kraal	Most urine is 'lost'	Dry dung	Fertilization
Zero grazing, dung removal	Urine can be collected	Wet dung	Digestion, fertilization
Zero grazing, daily flushing	Dung + urine + water	Liquid manure	Digestion, irrigation, fish farming
Zero grazing, scraping	Dung + urine	Slurry	Digestion, fertilization
Zero grazing, bedding floor	Dung + some urine + bedding	Farm-yard manure	Composting, fertilization
Zero grazing, slatted floor	Dung + urine	Slurry	Digestion, fertilization
For pigs:			
Slatted floor (wooden pens)	Urine can be collected	Wet dung	Digestion, fertilization
Slatted floor, slurry storage	Dung + urine	Slurry	Digestion, fertilization
Solid floor, daily flushing	Dung + urine + water	Liquid manure	Digestion, irrigation, fish farming
Solid floor with bedding	Dung + some urine + bedding	Farm-yard manure	Composting, fertilization
For poultry:			
Free range with night pen	Dry manure	Dry manure	Fertilization
Layers in cages	Wet manure if fresh	Wet manure	Fertilization
For all livestock:			
Deep litter	Dung + urine + much bedding	Farm-yard manure	Composting, fertilization

1 Digestion is described in Chapter 5 and other manure treatments are described in Chapter 6.

Dung and urine of confined animals can be readily collected. In kraal systems, animals have some confinement which allows collection of dung but, as the animals are often kept on bare soil, urine cannot be collected and also, the dung is subject to higher nitrogen losses (Figure 11).

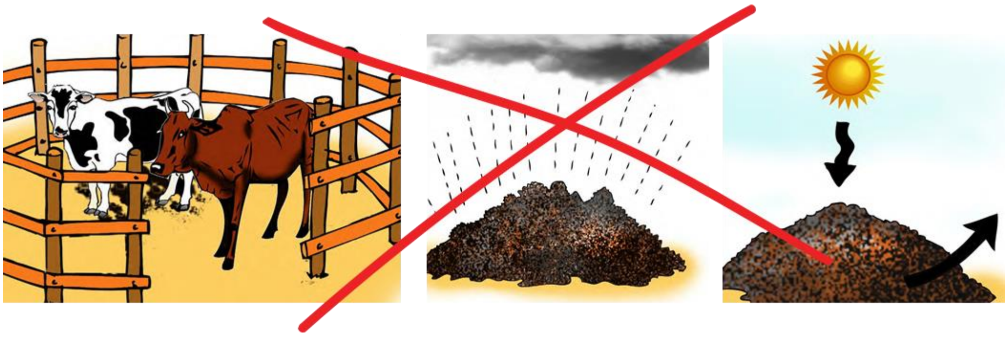

Figure 11. Nutrients are washed away and nitrogen is lost to the air from uncovered dung. (source: ILRI)

Flooring facilitates collection of both dung and urine (Figure 12 and 13). Similarly, manure stored in roofed houses is less exposed to nitrogen losses through volatilization. Roofing also prevents run-off and leaching losses of minerals due to rain.

Figure 12. Bad flooring makes it hard to collect dung and urine, and is very uncomfortable for cattle to stand or lie on.

Figure 13. Bedding affects the nutrient content of farm-yard manure.

Manure nutrient content depends on what is collected together with the manure. Bedding material, feed leftovers, flushing water, feathers, soil, etc. collected together with manure will affect the nutrient content (Figure 13).

Preventing urine discharge

Because urine is liquid it can easily get lost. Collecting urine with the dung to form slurry is the easiest way, but often not very feasible on smallholder farms. Urine can also be captured through the use of bedding materials.

Bedding materials absorb the urine. Moreover, these materials contain residual plant food, adding to the overall nutrient value of the compost (Figure 14).

The procedure is as follows:

- Chop or shred the materials (dried rice straw/rice stubbles, grass clippings, uneaten green feeds, etc.) so that they are easier to spread and will decompose faster. Coffee hulls and saw dust can also be used.

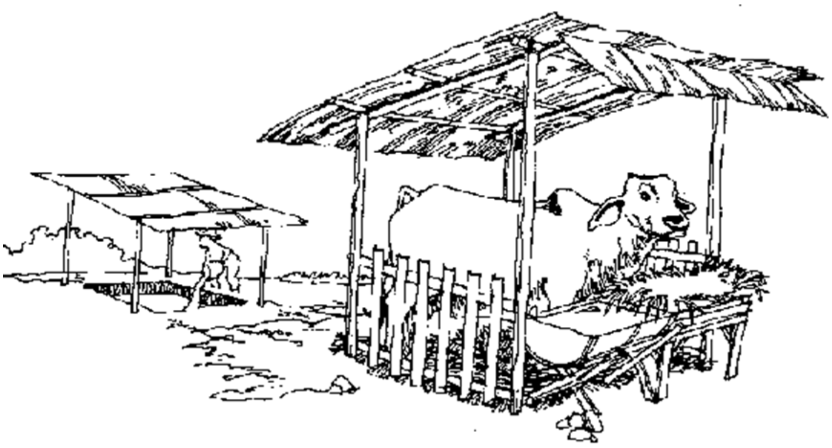

Figure 14. Saturated with urine the bedding mixed with dung is composted in a compost pit. [source: 2]

- Spread a 15 cm layer of litter bedding over the floor space. Allow manure and urine to accumulate.
- After 3-4 days, the bedding materials will have been fully soaked with urine. Mix them so as to incorporate the manure. Remove the mixture and put it in a pit or a pile fully covered to conserve the nutrients. The compost is ready for use in one and a half months or less.
- Provide fresh bedding materials and repeat the previous steps.

This simple method comes close to the principles of a deep-litter system.

3.1 Deep-litter system

These are systems where layers of bedding material are repeatedly spread on older layers as they get soiled. This system is most common in poultry farms, though it is also used for pigs, cattle and small ruminants (Figure 15). The manure usually breaks down gradually and composts sooner or later.

Figure 15. Finishing beef cattle in a deep-litter system.

When manure is mixed with bedding material (e.g. in deep litter systems with lots of straw or wood shavings), there will be an increase of nitrous oxide emission and a decrease of ammonia emission. The total emission of nitrogen gases tends to be higher in deep litter systems, compared to the emissions from slurry storage under slatted floors.

Deep-litter management involves:

- Providing proper aeration of the litter: in poultry systems, the chickens will take care turning much of the litter, but it must be monitored and areas that are missed or become caked, turned.
- Providing proper ventilation: cross-ventilation and open eaves are ideal. Ensure no drafts exist, particularly over roosts. Excess moisture and ammonia gasses must have a means of escape.
- Ensuring a correct moisture balance: moisture is essential to the process. Droppings consist of 85 % water, making it less likely that the litter will become too dry than too wet. Wet litter is a recipe for sick chickens. Prevent any water spills from drinkers and add litter when necessary to prevent matting.
- Animal health is improved through the use of 'all-in, all-out' management, where the manure is also removed from the house after every production round.

4 Manure Storage

WHAT FARMERS NEED TO KNOW

- Proper storage preserves crop nutrients until the time of application.
- Storage roofing prevents runoff of nutrients to the soil and water.
- Storage flooring prevents leaching of nutrients into the soil and water.
- Air-tight storage covering prevents nutrients from volatilization to the air.

Manure storage is necessary to bridge the gap between the moment of excretion and the optimal moment of application on cropland. This is also the period in which nutrients are very susceptible for losses to the environment. Therefore proper manure storage plays a key role in preventing environmental pollution and other nuisances like odor and flies.

4.1 Stackable manures

Major emissions from prolonged storage of stackable manure in heaps will be NH_3 and N_2O although some CH_4 emission can be expected from anaerobic spots within the heap. These emissions can be reduced by limiting the contact surface between manure and air by stacking and compressing the heap and by protecting the manure against the influence from wind, water and sunlight.

Fresh poultry manure needs to be composted for some weeks or months before it can be used as fertilizer. The maturation time allows the mineralization of organic matter so that the nutrients are in a form that is available for crop uptake. The nitrogen amount in the manure tends to decrease over time, because NH_3, N_2 or N_2O are emitted or because soluble N is leached by rainwater. The P_2O_5 and K_2O can also be lost by leaching from rainfall, further reducing the usefulness of the manure. To reduce these losses, the ***manure should be covered during storage.***

Kraals

These enclosures are often used as *in-situ* fertilization of arable land by moving the kraal regularly. Soil fertility of a larger area, used for grazing, is partially concentrated on the arable land, thus enabling crop production in resource-poor situations. Losses through leaching will be slightly higher than during grazing as equivalent N and K fertilization rates are increased. [10]

Figure 16. Uncovered manure pile next to the kraal leading to high nutrient losses. [source: 27]

Dry lot storage

If urine is not collected and bedding is sparsely used, losses of N and K will be high as most urine is lost. Urine collection will minimize K losses but N losses will often remain high as volatilization will increase, though this is dependent on climatic conditions, storage time and storage method. Using bedding, with sufficient absorption capacity to capture urine, might reduce N losses by ca. 15 % of the mineral N. [10]

4.2 Liquid manures and slurry

Liquid manure is often the result of flushing (Figure 10). The DM content of the mixture of urine, dung and a lot of water is not more than 5 %. Because of its high volume, liquid manure needs a large storage capacity e.g. lagoons. Storage is redundant when the liquid manure can immediately be used e.g. as a source for irrigation or for fertilization of fish ponds. A practice case of such application is described in paragraph 7.7.

Slurry originates when dung and urine are stored together indoors under the floor, or transferred to an outdoor silo or pit. The floor may be solid with regular scraping or slatted, in which case the excretions immediately drop into the storage. In dairy, often flushing water from an adjacent milking parlor is also added. Except for broilers, this is the main system in intensive livestock systems.

Slurry becomes liquid manure when water is added and DM goes below 5 %. When no water is added and DM stays within the range of 5 - 10 %, it is still slurry.

Volatilization losses are dependent on the level of ventilation, depth of storage and storage time, but often range between 5 and 35 % of the total N excreted [10]. The major emission from prolonged storage of slurry in deep pits or silos will be CH_4. This emission can be reduced by anaerobic digestion of the fresh slurry in a closed silo (see next chapter).

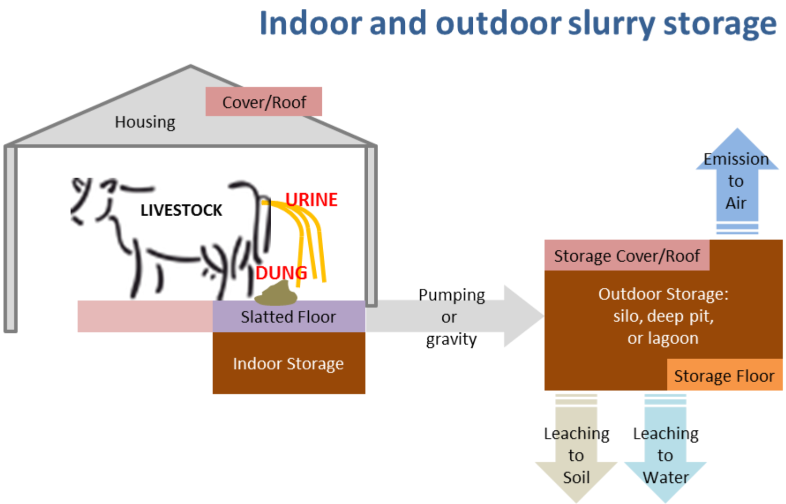

Figure 17. Overview of slurry handling and storage.

Lagoon

Lagoon systems are quite common at large livestock farms to store liquid manure (Figure 18). Except for the surface, lagoons are anaerobic, which makes them major CH_4 emitters. Organic material is decomposed, thereby mineralizing part of the nutrients. The liquid phase is either discharged into surface water or used for irrigation. The main problems are related to the discharge into surface water, leaching through the lagoon bottom if not waterproof, and odor. High NH_3 emission will occur as a major part of the N is in mineral form. Next to CH_4, also some N_2O emissions are common [10]. Lagoons can be open or covered with a floating cover. In trials with bioslurry the effect of roofing showed a N loss of 25 – 30 % of initial N content, while that from uncovered bioslurry was 60 – 70 %.

Figure 18. Cattle slurry stored in an uncovered lagoon.

Table 5 gives an impression of some manure compositions that can be encountered after storage under tropical conditions. Since animal species, their production level, their diet, their housing system, length of storage period and the storage conditions are unknown; the figures in this table are purely illustrative and should not be used for calculations. Only analysis of a uniform sample (Figure 19) will provide accurate data for manure nutrient contents. How to take representative samples from solid and liquid manure is described in Chapter 7.

Table 5. Composition ranges of some manure types after storage under tropical conditions in grams per kg of fresh product (g/kg = kg/ton) [after 21].

Manure type	DM %	N	P_2O_5	K_2O	CaO
Cattle dung	60 – 66	17 – 20	5 – 37	13 – 25	9 – 11
Farm-yard manure	46 – 62	05 – 20	4 -15	12 – 84	3 – 27
Sheep and goat droppings	48 – 60	15 – 18	9 – 10	14 – 17	9 – 10
Solid pig manure	50 – 65	15 – 24	9 – 10	14 – 38	13 – 15
Dry poultry manure	87 – 90	23 – 25	23 – 39	10 – 37	6 – 40
Composted manure	> 60	5 – 16	3 – 5	50 – 74	46 – 54

$P_2O_5 = P \times 2.29$ $(P = P_2O_5 / 2.29)$ $K_2O = K \times 1.2$ $(K = K_2O / 1.2)$

Figure 19. Only taking samples for nutrient analysis will reveal the true nutrient content of manure.

5 Anaerobic Digestion

WHAT FARMERS NEED TO KNOW

- Biogas substitutes for fossil fuel and biomass fuel.
- A biodigester needs to be fed with fresh manure every day of the year.
- Digestion of manure does not change the nutrient content of manure; bioslurry is still a valuable fertilizer.

Production of biogas through anaerobic digestion of organic material e.g. manure, is a relatively simple technology that can be implemented at industrial, village and farm household scales. Biogas substitutes for fossil fuels and biomass fuels. The gas can either be used directly as a heat source for cooking or lighting, or indirectly by powering a generator to produce electricity. One cubic meter of biogas is equal to approximately 1 liter kerosene, net 2 kWh electricity, 4 kg firewood and 6 kg paddy straw.

5.1 Purpose, Principle and Requirements

Anaerobic digestion (AD) is a biochemical process during which complex organic matter is decomposed in absence of oxygen, by various types of anaerobic microorganisms. The process of AD is common to many natural environments such as the marine water sediments, the rumen of ruminants or the peat bogs. In a biogas installation, the products of the AD process are biogas and digestate (Figure 20).

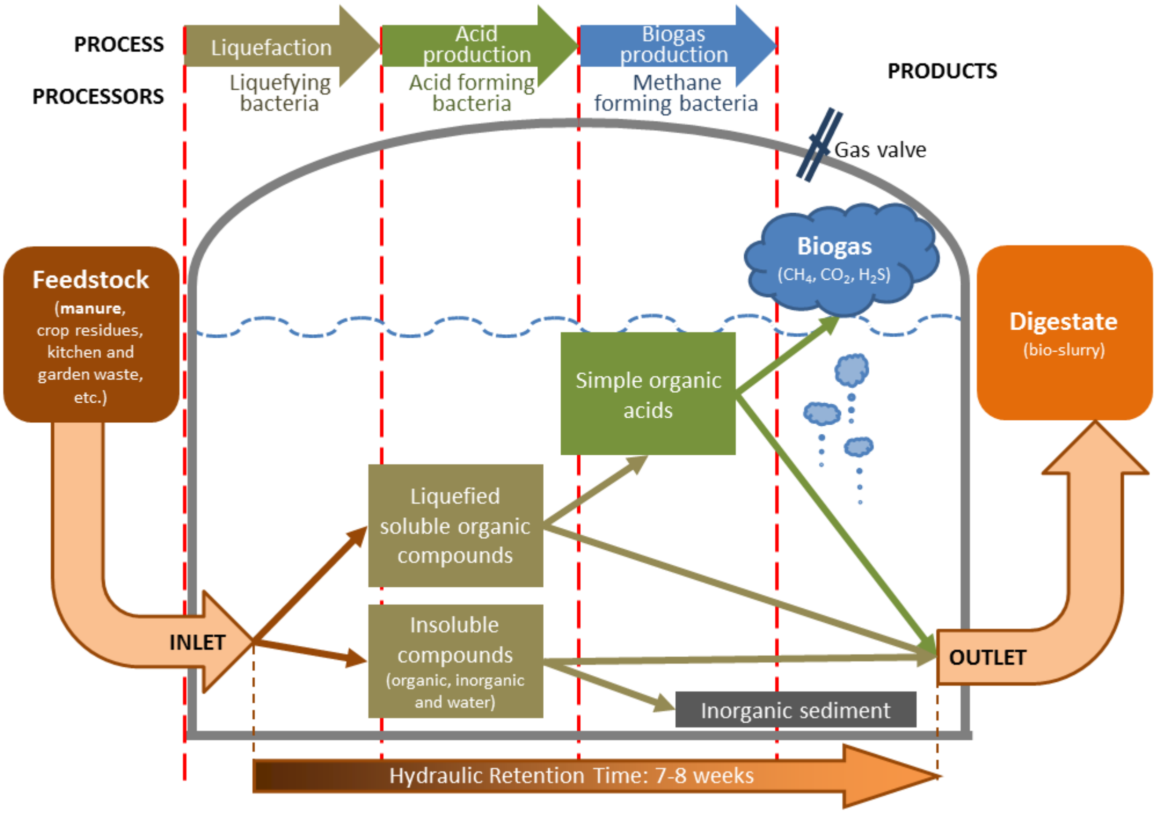

Figure 20. Schematic overview of an anaerobic digester and the sequence of bacterial processes that end with the production of biogas. [after source: 25]

Gas production takes place in an oxygen-free (anaerobic) environment with an average temperature of about 35 – 40 °C. The ambient temperatures should remain over 15 °C. If the substrate is a homogenous mixture of two or more feedstock types (e.g. animal slurries and organic wastes), the process is called "co-digestion". Table 6 shows the composition of biogas and the ranges of the different gases. About 25 to 30 % of organic matter is converted into biogas while the rest becomes available in the digestate or bioslurry. A second coproduct of biogas is the sediment also called sludge. The sludge on the bottom of the digester contains a high fraction of mineral nutrients. As sludge production is low, it can remain in the digester for years before use.

Table 6. Composition of biogas. [5]

Composition	Proportion (%)	Composition	Proportion (%)
Methane - CH_4	50 – 70	Hydrogen - H_2	0 – 3
Carbon dioxide - CO_2	30 – 45	Oxygen - O_2	0 – 3
Nitrogen - N_2	0 – 3	Hydrogen sulphide - H_2S [1]	0 – 3

1 H_2S is highly toxic for humans; a concentration of more than 500 – 1,000 ppm (0.05 – 0.1 %) is lethal. H_2S is harmful when biogas is used in internal combustion engines.

Once gas production starts, the user has to feed the biodigester daily. The digester size is determined by the daily fed quantity of feedstock and the time needed for the full digestion of the feedstock inside the digester (called the hydraulic retention time -HRT). For simple domestic biogas installations, applied HRTs vary from 45 days in warm areas to 55 days in temperate areas. So, the entered feedstock should remain in the digester for this period to release most of the biogas. HRT is also the time needed for the slurry to traverse from the inlet side of the digester to the opposite outlet side. The daily feedstock input times the HRT indicates the digester size.

Requirements

To successfully operate an anaerobic digester, it needs a constant in-flow of feedstock (manure) and, depending on the DM content of the feedstock, water. Both should be available at all times. This might cause continuity problems in 'all-in – all-out' livestock systems, where barns are left empty in between for a period of time in order to control animal diseases and pests. Also, the available quantity of manure from cattle is not constant when cattle are grazing during the growing season and are only kept in confinement during limited periods of time e.g. dry periods or extremely wet periods.

5.2 Digester Types

There are many different designs of small-scale biodigesters in use today. Broadly, they can be classified as: fixed-dome digesters (Figure 21), floating drum digesters, synthetic bag digesters and channel digesters. In principle, the functioning of all these models is the same, only the shapes may differ. Whereas in cold and temperate climates a digester may need additional heating, in the tropics and sub-tropics this is often not an issue, with maybe the exception of locations at high altitudes.

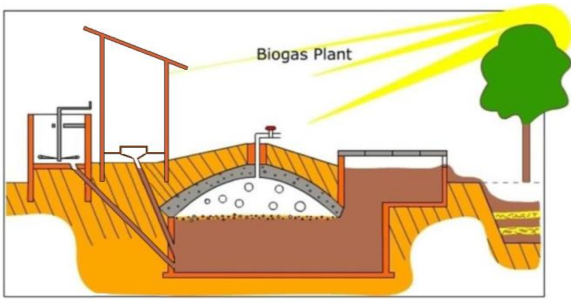

Figure 21. Small-scale fixed-dome digester. For domestic use a lavatory can be added next to the inlet. (source: SNV)

Large-scale digesters can be covered lagoons or closed silos with a provision to capture the biogas produced by anaerobic digestion of liquid manure. Covered lagoons for slurry storage are associated with relatively large-scale intensive farm operations in extensive farming areas. These low-cost lagoons with lined bottoms and floating covers require large land areas because the HRT for the diluted manure is about 8 – 9 weeks.

Digesters with process control are more sophisticated and more compact. These digesters are closed vessels (silos) heated to about 40 °C, and continuously stirred, which all together reduces the HRT for the manure to about 3 weeks. The land area required for these digesters is much smaller than for covered lagoon digesters.

Figure 22 summarizes of the different factors influencing the choice of biodigester [8]. It also shows that the DM content of the feedstock should be below 12 – 13 % in order to be suitable for AD.

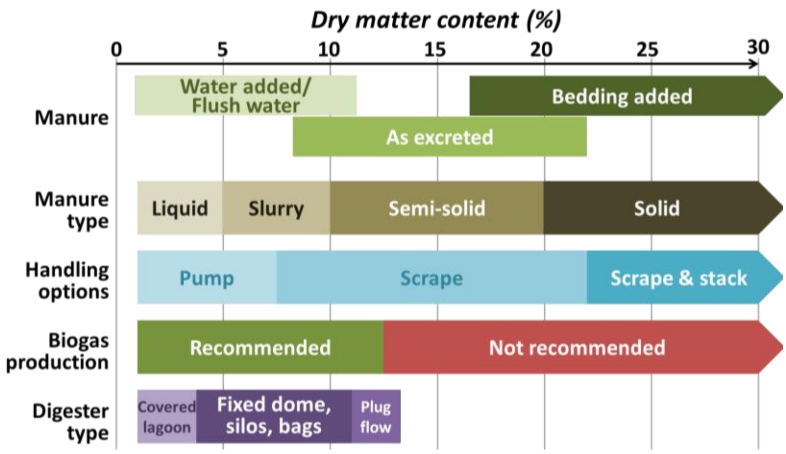

Figure 22. Schematic overview of manure characteristics towards AD decision making.

5.3 Biogas Production

Although biogas can be generated by a wide range of organic material, cattle dung is best suited as a substrate for small installations; the digestion process is robust and the material is abundantly available on many farmyards. For a biogas plant to be attractive to a family, it should be able to provide at least 0.8 to 1 m^3 biogas daily. To generate this amount of biogas, the household should have 20 to 30 kg of fresh dung available on a daily basis. Table 7 gives an indication of the feedstock quantity needed for several sizes of domestic or small-scale digesters.

Table 7. Small-scale biodigester sizes, their input requirements and biogas outputs. [4]

Biodigester size	Initial feeding with **cattle** dung	Daily **cattle** dung feedstock	Water to mix[1]	Use of biogas stove	Use of biogas lamp
4 m^3	1,500 ltr	20-40 kg	20-40 ltr	3.5 to 4 hrs	8-10 hrs
6 m^3	2,300 ltr	40-60 kg	40-60 ltr	5.5 to 6 hrs	12-15 hrs
8 m^3	3,000 ltr	60-80 kg	60-80 ltr	7.5 to 8 hrs	16-20 hrs
10 m^3	3,800 ltr	80-100 kg	80-100 ltr	9.5 to 10 hrs	21-25 hrs

1 To reach a required 7.5 – 8 % DM of the substrate, this assumes a DM content of the fresh cattle dung of around 15 %. When urine is also collected and the cattle are fed a low-protein diet, water may not need to be added.

Gas yields differ depending on volumes, type of manure and digester technology. Manure from pigs and birds yields more gas than from cows (Table 8). Chicken litter contains high levels of ammonium, which is toxic for biogas bacteria, and may contain sand and other sediment-forming elements. Therefore, poultry manure should only be used in small quantities. Excess nitrogen may stall the AD process. Pig manure also forms sediments. Cow manure also contains sand that forms sediments and fiber that forms a floating layer in the digester.

Table 8. Biogas production for various feedstocks. [23]

Feedstock	m^3 biogas / ton DM
Cattle manure	200 – 300
Pig manure	250 – 500
Chicken manure	310
Sheep manure	300 – 400
Rice straw	550 – 620
Maize straw	400 – 1,000
Vegetable wastes	400
Kitchen waste	400 – 1,000

Example

How much fresh cattle dung do you need to produce 1 m^3 of biogas per day?

Assume 1 ton DM cattle manure produces 250 m^3 biogas (Table 8). DM content of fresh cattle dung is assumed to be 16 % (Figure 17). So, 1 ton DM cattle manure equals (1,000 kg / 16 % =) 6,250 kg FM cattle manure.

To produce 1 m^3 biogas you need (6,250 kg FM / 250 m^3 biogas =) 25 kg FM cattle manure. This quantity approximates the daily amount excreted by a 500-kg crossbred or two small local breed cows of ca. 250 kg live weight (Table 3). For this situation a 4 m^3 digester would be sufficient (Table 7).

5.4 How to keep a steady gas flow

Since anaerobic digestion is a biological and bacterial process, it is very susceptible to disruptions. To maintain a steady biogas flow, the bacteria should be fed continuously with a fresh substrate in an oxygen-free environment. It is easy to disturb this process if you:

- Don't add fresh material every day;
- Add too much fresh feedstock (or too rich material);
- Add dung feedstock that is too old;
- Add too much water, the DM content should be around 7.5 %;
- Add water with detergents (soap) or disinfectants;
- Add (human or animal) excreta with medicine residues; especially antibiotics (AB) are very harmful, beware of discharged milk from cattle treated with AB;
- Let oxygen in e.g. by leaving the gas valves open or not repairing leaks.

Practice Case

Surplus biogas for sale

Biodigesters may produce more biogas than needed for daily family use e.g. cooking and lighting. When a distribution network is lacking, this surplus gas is either discharged into the air or flared off. This is a waste of valuable renewable energy and a harmful contribution to global warming! But how to store it instead? Portable gasbags offer a cheap and easy-to-handle solution. The bag (as shown) contains 2 cubic meters of biogas, enough for at least 4 hours household cooking. With the bags comes the opportunity to sell the gas to families without a biodigester; so they can cook with clean burning biogas also.

It goes without saying that the bags should be <u>handled with care</u> since their content is highly inflammable.

Go for more information to (B)energy (http://www.be-nrg.com/)

6 Manure Treatment

WHAT FARMERS NEED TO KNOW

- If mechanized application is not possible, composting is the best way to store manure and ease its transport and field application.
- Slurry and bioslurry can very well be composted.
- Drying (bio-)slurry loses 50 % of the total nitrogen.

The manure characteristics can be changed by different manure treatments, e.g. mechanical separation of slurry results in solid and a liquid fraction that can be used for different purposes. The liquid fraction can be used for fertilization and the solid fraction can be used for composting or biogas production.

The chart below shows some reasons for treating manure.

Objective	Outcome	Treatments
• Reduce volume	Easier handling, less storage capacity needed, and less transport costs	• Dehydrating • Physical separating
• Improve applicability	Easier handling and more possibilities for specific application	• Additions • Physical separating • Composting
• Increase value	High-concentrated fertilizers	• Refining

Note: these are human actions which can be implemented before, during or after storage.

Mechanization of agriculture makes the application of slurry in the field more convenient. In the context of many developing countries agricultural mechanization is not practical because of scattered and fragmented holdings including the topography of the landscape. Slurry transport to the field is often difficult because of its liquid nature. In those cases dehydration or composting may be the only way to utilize it. But dehydration through solar drying volatilizes the ammoniacal form of nitrogen. Composting is thus the best alternative.

A special treatment is preparing manure tea to be used as a top dressing for certain crops.

6.1 Dehydration

Air drying is an method to reduce the volume of manure; most applicable for manures low in DM like slurry and bioslurry (Figure 23). A major disadvantage of air drying is that practically all mineral N is lost through ammonia volatilization. However, if discharge into the environment is the only alternative, losing the ammoniacal N is always less harmful than losing all nutrients!

A precondition for this kind of treatment is the availability of enough area with waterproof flooring to spread out the manure. Infiltration by rain should be prevented either by covering the drying area or by restricting the drying periods to the periods with no or low rainfall.

Figure 23. Air-drying of bioslurry on shallow plateaus on a large pig farm in Thailand.

The final product is a thin manure crust that can be ground and, in bulk or in bags, easily be (sold and) transported to the place of application. Manure in this form is easy to handle and therefore very suitable for small-scale use, in which also manual application is very well possible.

Active drying using large fans is more common under battery cages with layer hens.

Figure 24. Mixing the top layer of a kraal to dry cattle manure.

Figure 25. Liquid fraction flowing out of the separator.

A very specific manure treatment was seen to dry dairy cattle manure in a covered kraal in the Costa Rican highlands. Very steep hill sides hinder a mechanized application of the manure. However, a dry (and light-weight) manure product allows manual application on the steep permanent pastures. To produce such a product the farmer mixes the top layer of the covered kraal (consisting of dung and some top soil) twice a week with a rotary tilling machine used in horticulture (Figure 24).

6.2 Physical Separation

Physical separation is a mechanical treatment mostly applied to slurries to squeeze out moisture and thus separate manure into a liquid fraction (Figure 25 and 26) and a solid fraction. Although separation does not affect the chemical composition, it does affect the nutrient content of both fractions. Since the mineral N content is higher in urine and the P_2O_5 content is higher in dung, after separation the liquid fraction contains more N and the solid fraction will contain more P_2O_5 (Table 9). On farms with limited fertilizer resources this method opens the possibility to use the liquid fraction on crops with a relatively high N demand and to use the solid fraction on soils with relatively low P_2O_5 levels.

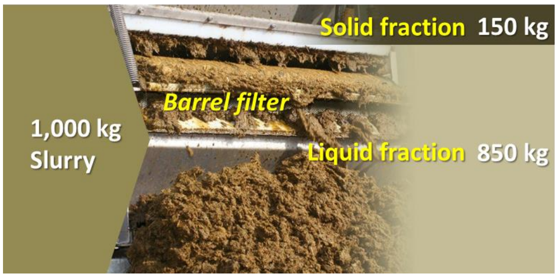

Figure 26. Slurry separation with a barrel filter.

Table 9. Nutrient content (g/kg) of unseparated slurry and of the fractions after separation with a barrel filter. [22]

	kg	DM (%)	OM (%)	N total	N mineral	N organic	P_2O_5	K_2O
Original slurry	1,000	7.7	6.1	3.3	1.6	1.7	1.0	5.7
Solid fraction	153	22.1	19.7	4.0	1.4	2.6	1.6	5.1
Liquid fraction	847	5.1	3.6	3.1	1.6	1.5	0.9	5.7

Diluted with water the liquid fraction can be used to irrigate crops. The undiluted liquid fraction is also suitable as fertilizer in fish farming.

The solid fraction, being a stackable product, is easy to store and to transport (e.g. for sale).

6.3 Additions

Additions to manure are meant to make the manure product more suitable to handle. Many smallholder farms are equipped with an anaerobic digester producing biogas and bioslurry. The bioslurry is often difficult to handle by these farmers because it is very liquid and crops may be far away and/or difficult to reach. Adding bedding materials like straw (Figure 27) or dry crop residues to the bioslurry to capture a lot of the moisture eventually produces a stackable and therefore easier to handle manure product with an increased OM content. It is a kind of pre-stage of composting.

Figure 27. Bioslurry to mix with straw. (source: SEI)

6.4 Refining

Refining is a high-tech solution to harvest nutrients (minerals or compounds) from organic manure. The harvested materials can either be used for fertilization or for further bio-chemical processing by the bio-based industry. The high-tech character of refining supersedes the practical use of this treatment in this manual.

6.5 Composting

Composting is an attractive proposition for turning on-farm organic waste materials into a valuable soil amendment and fertilizer resource. Composting is suitable in all farm situations, large or small and with solid and liquid manure types.

Composting is the natural process of fermentation or decomposition of organic matter by microorganisms under aerobic conditions. Compost is a rich source of organic matter. Soil organic matter plays an important role in sustaining soil quality, and hence in sustainable agricultural production. In addition to being a source of crop nutrients, it improves the physico-chemical and biological properties of the soil (e.g. water-holding capacity and erosion resistance).

Compost production is labor intensive and demands regular attention. Collecting the composting materials, setting up the heap, regular watering and repeated turning of the heap, when not mechanized, make composting a very labor intensive activity.

The microorganisms in the compost pile need carbon and nitrogen in the proper proportion for their growth and activity. Ideally the carbon to nitrogen ratio (C/N ratio) should be in the range of 20 : 1 to 30 : 1, with the higher number representing carbon. Having the proper C/N ratio will ensure the heap is active and the process of transforming the materials into humus will happen. A few materials, such as cattle manure mixed with bedding, soybean shells, and legume hay have C/N ratios close to the ideal range (see Table 10). Materials high in N are animal manures and vegetable waste; while those high in C are maize stalks, sawdust and hay. If too much green material is included, the heap will become rotten and much of the N will be lost as gas; if too little green material is used then the decomposition process will be too slow and tough materials, weed seeds and pathogens will not be broken down or only after a long period.

Table 10. C/N ratio of much used materials for composting. [6]

Cattle manure	20 : 1	Legume hay	25 : 1
Sheep/goat manure	14 : 1	Maize stalks	60 : 1
Chicken manure	10 : 1	Straw/hay	90 : 1
Vegetable waste	12 : 1	Sawdust	200 : 1
Grass/weeds	20 : 1	Newspaper	800 : 1

Slurry is an excellent material for increasing the rate at which refuse, crop waste, garbage, etc. are composted. It also provides moisture to the compostable biomass.

Regularly turning the compost inside out ensures a good oxygen supply and ensures a good composting process of all the mixed layers. The main disadvantage is the high loss of mineral N through the volatilization of NH_3 and N_2O emissions.

Characteristics of mature compost:

- Coarse materials become finer over time until a fine, loamy material is produced;
- The different materials are no longer recognizable;
- The material has a slight ‘earthy’ and inoffensive smell;
- Temperature drops and the compost is cool;
- Compost is dry.

Composting Methods

There are different methods of composting. The two most common are:

1. **Heap or pile method**, suitable for large-scale processing and for small-scale operations in areas with higher rainfall.
2. **Pit method**, suitable for small-scale processing in areas with low rainfall and a long dry season and for composting of liquid manures.

Building and maintaining a small-scale compost <u>heap or pile</u>:

- Make a base 30 – 45 cm deep and 2 meters wide with any convenient length. Loosen the ground and lay some coarse plant materials such as twigs. This will ensure good air circulation and drainage.
- Put a layer of 30 cm of dry vegetative matter, chopped into small pieces. Small pieces decay faster.
- Add a 10 cm layer of old compost, animal manure or slurry. This will add extra bacterial and fungi to speed up decomposition.
- Add a 10 cm layer of green materials. Try to maintain a ratio of 1 part greens to 3 parts of dry matter. Kitchen waste, such as fruit and vegetable peelings, decomposes quickly.
- Add a sprinkling of top soil from the top 10 cm of cropped land.
- Ash can then be sprinkled onto these layers.
- Water the whole pile well.
- Repeat all these layers except the first layer of twigs until the heap reaches 1 to 1.5 m high.
- The heap should be covered to protect it against heavy rain as this will wash away nutrients. A 10 cm layer of top soil may be applied as this may reduce nitrogen loss from the compost.
- A long sharp-pointed ‘thermometer’ stick (as in Figure 28) is then driven into the heap at an angle and used to check on heap condition from time to time and to allow air to enter the heap through the hole of the stick.
- Water the heap twice a week. If the heap is too dry, the microbes become dormant and the composting process will slow down. If the heap gets too wet there will not be enough air and the microorganisms die.
- The pointed stick (Figure 28) should be used to measure temperature. The stick should feel slightly too hot when removed after a few days. If it does not, this may be because decomposition has not started and more air or water may be needed. If the heap is very hot, decomposition is taking place but the excessive

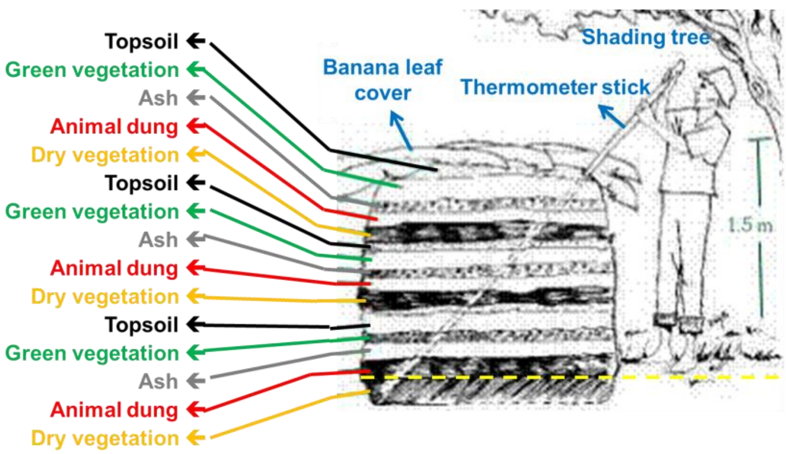

Figure 28. Layer build-up of compost heap. [source: 25]

heat may kill the organisms and the heap should be compacted to reduce airflow within the heap or water should be added to cool it down. If the stick is white, it indicates a fungus is present 'fire fang', which is an indication of poor decomposition process and water should be added.

- The compost heap should be turned every 1 – 2 weeks so that the materials on the outer layers of the heap are put in the middle of the heap. Turning will help to aerate the heap and will ensure that the materials on the outer layers will decompose as well.

The heap should always be covered (for example with banana leaves) after turning to protect the wash-away of nutrients by rain. Duration of compost making varies depending on the quality of materials used, but on average 6-8 weeks is sufficient to prepare provided the material is not too fibrous.

Building and maintaining a small-scale compost pit (for liquid manure):

- Prepare two compost pits 1.2 m wide and 0.6 m deep, and as long as you need for the amount of materials you have; and, in case of slurry composting: with a combined volume equal to the total digester volume, by the side of the biogas plant and at least 1 meter away from the plant
- Spread a thick layer of dry materials (15 – 20 cm), such as dry forest litter, waste grasses and straw, leftovers of animals feed and weeds collected from the fields, at the bottom of the pit to absorb the moisture of the slurry and reduce the leaching of nutrients into the groundwater.
- Let the slurry flow onto the dry materials so that the dry material becomes soaked with the moisture present in slurry (Figure 29).
- Cover the slurry with a thin layer of straw, stable waste or any other dry material. This is done to prevent slurry from drying and preserves the plant nutrients.
- Next day, let the slurry flow into the pit. If possible spread the slurry equally over the dry materials in the pit and cover it with the same materials as used previously.
- Repeat this process every day till the pit is full and cover it with dry straw/materials or a thin layer of soil and leave it for a month.
- Provide shade to the compost pit, either by making a bamboo structure and planting it with creeping vegetables or by planting fruit trees like banana, fodder trees, green manuring plants or pulses like horse gram. The shade prevents evaporation loss of nutrients from the compost pit.
- After a month, turn the compost in the pit and cover it with additional dry materials or a thin layer of soil.
- Turn the compost again after 15 days and cover it as before.
- Start filling the second pit after the first pit is full. Follow the same procedure in filling the second pit.

Figure 29. Bioslurry flowing into a (covered) compost pit. (source: ILRI)

Storage

Mature compost should be kept covered to protect it from rain and sun. If the compost is kept for too long before use it will lose some nutrients and may also become a breeding place for unwanted insects.

You can produce a regular supply of compost by digging three pits (or piling three heaps) side by side. Every 2 to 3 weeks, turn the compost from one pit into the next one, and start a new compost pile with fresh vegetation in the empty pit.

Practice Case

Feedlot Compost

Because of their size and the large daily produced quantity of fresh manure, many feedlots for finishing beef cattle struggle with sound manure management, often leading to environmental pollution and a waste of valuable resources. The Argentinian brothers del Barrio, owning the El Trébol farm enterprise with about 30,000 head of beef cattle, of which 12,500 are kept on feedlots, successfully utilize these valuable resources; not just because it generates additional income but because it reduces pollution of their environment.

Every day they scrape off the top layer of the 50 feedlot pens and pileup this mixture of manure and topsoil to be composted. The final product is compost containing 65 % organic matter and many valuable crop nutrients. The compost is sold as organic fertilizer to horticulturists and retailers in the area of Buenos Aires. The del Barrio brothers herewith demonstrate that even in high-density cattle situations like the feedlots, manure management is possible and can be profitable.

7 Application of Organic Fertilizers

WHAT FARMERS NEED TO KNOW

- Manure substitutes for (expensive) synthetic fertilizers.
- Manure must only be applied at the time the crops need the nutrients.
- The application dose depends on the crop requirements and soil fertility, and on the available amount of nutrients in the manure.
- To know the nutrient content, soil and manure need to be analyzed for N, P and K.
- Application of synthetic fertilizers is complementary to the use of manure.
- (bio-)Slurry should not be applied to fruits and vegetables grown for fresh consumption.

Because of its site specificity, integrated manure management may result in different manure products to be used in the final and essential stage of the manure chain: the application to crops or aquaculture.

Crops need nutrients for different functions (Table 11).

Table 11. Importance of nutrients to crops.

Nitrogen (N)	Phosphate (P_2O_5)	Potash (K_2O)
Increases growth and development of all living tissues.	Helps in early maturing by stimulating flowering.	Enhances a plant's ability to resist diseases.
Improves the quality of leafy vegetables and fodder and the protein content of the food grains and makes them green.	Helps in seed and fruit development.	Assists carbohydrate translocation and water utilization by stomatal regulation.
Helps uptake of phosphate, potash and micronutrients.	Helps for the growth and development of root of the plant.	Resists wilting and lodging of plants.

Crop nutrient uptake is always in an ionic form with soil moisture. To crops it doesn't matter whether the nutrient source is an organic or inorganic fertilizer. Due to the decomposition (mineralization) of OM, eventually organically bound nutrients also become available in ionic form.

7.1 Principles of fertilization

Soil is like a barrel containing many macro and micro elements from which crops take up the quantity they need for their growth. If that quantity is not available in the root zone, crops will show reduced growth and eventually perish. Therefore, the **basic principle** to keep soils healthy and fertile is simple: **always replenish the amounts of nutrients that are harvested with crops.** This is fertilization. The challenge is to find the right balance between the crop demands and the nutrient supply by the soil as illustrated in Figure 30, balance A.

In order to keep the balance, you have to know the amounts of nutrients that are harvested and physically removed from the land (B).

At this point in the manual it is impossible to give an amount for each crop, since this depends on many factors. It is an important role for research and extension to provide the appropriate figures about the harvested amount of nutrients in locally common crops.

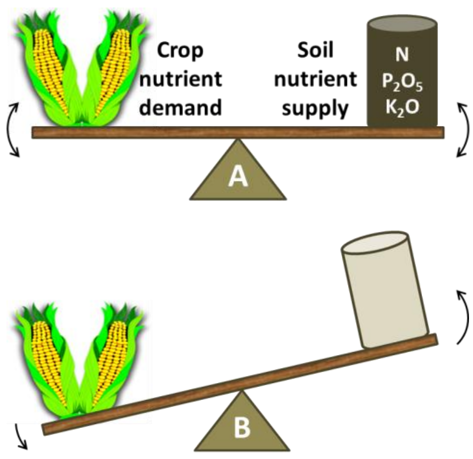

Figure 30. Balancing nutrient demand and supply.

Balance demand and supply

The first step to restore the balance is using livestock manure (Figure 31 C). As stated in the introduction chapter, recycling crop nutrients with manure is an essential step in the agricultural nutrient cycle. Manure not only contains crop nutrients, but is also an important source of organic matter, which is needed to keep soils healthy.

No fertilization or not enough fertilization will eventually lead to reduced crop growth (D), in which case the crops are mining the soil, finally resulting in depleted soils and poor yields.

When the nutrient supply with manure is not enough or not completely covering all the different macro nutrient demands (N, P_2O_5 and K_2O), an additional topping with synthetic fertilizer is applied (E). This must also be done in the case of an insufficient soil level of one or more secondary or micro nutrients. **A chemical soil analysis is therefore indispensable**.

Because of inevitable nitrogen losses (Figure 32), the Working Coefficient of nitrogen (WC-N) in manure never reaches 100 %. It is good agricultural practice to compensate for these losses by an additional application or a topping with synthetic nitrogen fertilizer. WCs of the nutrients in manures under local conditions should be provided by the local extension services based on local research.

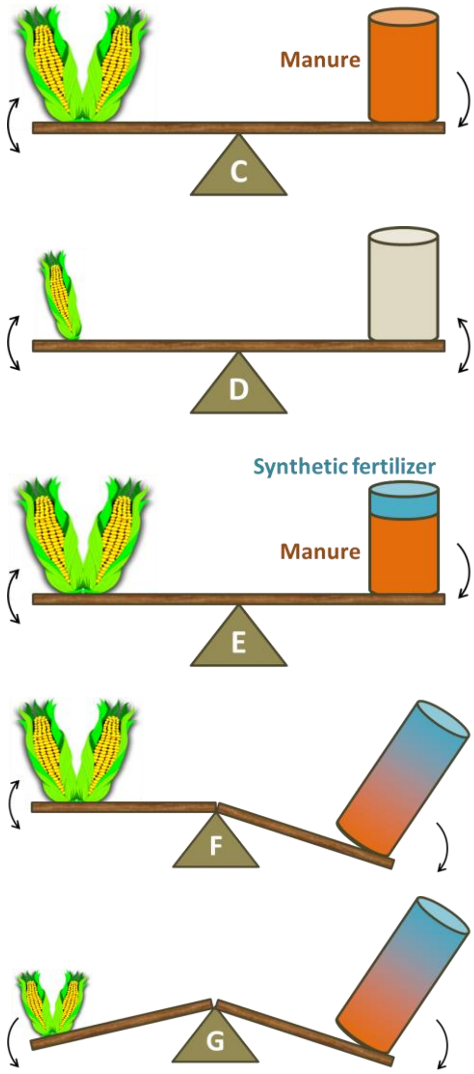

Figure 31. Balancing nutrient demand and supply.

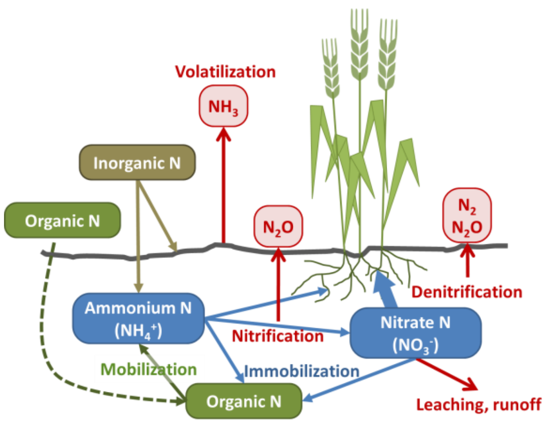

Figure 32 Nitrogen losses are inevitable and may occur at different stages between the moment of application and crop up-take.

Over-fertilization

Providing more nutrients than crops require in general does not increase crop production to the extent that it compensates the extra expenditures. Besides a possible luxury nutrient up-take, most of the surplus nutrients will be lost to the soil e.g. leaching to deeper soil layers (beyond the root zone) and groundwater (F). Eventually the environmental pressure may even cause reduced crop growth (G).

When large numbers of animals are concentrated in a relatively small area, there can be insufficient land for manure application. This is often the case with intensive livestock production in the vicinity of large cities. To avoid over-fertilization, the surplus manure must be transported to a region where it can be used as fertilizer on agricultural land. Dumping of large volumes of manure on small plots of agricultural land and thus largely exceeding crop demands, has to be avoided.

Note: in case of soil depletion, an extra dose on top of the crop demand may be applied in order to restore the desirable soil fertility status of e.g. phosphate.

Besides manure and synthetic fertilizers, N can also be added to the soil through the use of legumes. In a symbiosis with *Rhizobia* bacteria, legumes are capable of capturing N_2 from the air. This N is released to the soil when the crop remains of the legumes decompose (Figure 33). N fixation may be up to 150 to 300 kg per ha.

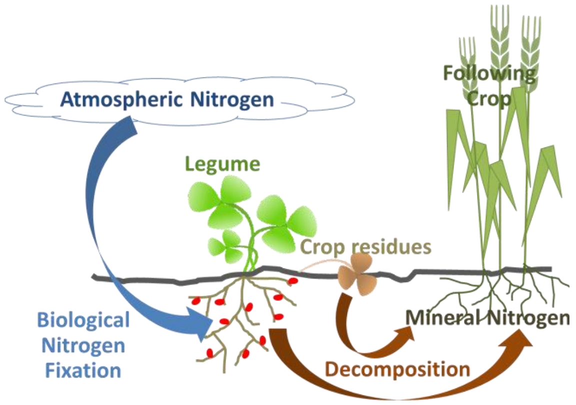

Figure 33. Principle of biological nitrogen fixation by legumes in symbiosis with rhizobia bacteria.

Figure 34. A dense cover crop (hairy vetch - Vicia villosa) provides good soil cover [source: 20].

Other fast-growing plants can be used as a catch crop, to capture residual soil nitrogen after harvest and provide extra organic matter; or as a cover crop to protection against soil erosion by wind and water (Figure 34). The following crop can profit from the nutrients that are released after incorporation into the soil and subsequent decay of the tissues of the catch crop/cover crop. [11]

Keep in mind that catch/cover crops also take-up water and thus reduce the available water resources for following crops.

On a farm scale nutrient demand and supply should be calculated for each crop taking into account the different requirements and contents of N, P_2O_5 and K_2O and also possible shortages of secondary and trace nutrients, on the basis of chemical analyses of soil and crop nutrient status.

7.2 Fertilizer value

Table 12. Total nutrient values of different types of organic fertilizer.

		Dry-Matter (%)	Kg per ton fresh matter (= g/kg)				
Manure type:			**N total**	**NH_4^+-N**	**P_2O_5**	**K_2O**	**Mg**
Solid manures [18]							
Solid cattle manure	Range	16 – 43	2 – 7.7	0.5 – 2.5	1.0 – 3.9	1.4 – 8.8	0.7 – 2.1
	Average	22	4.8	1.3	3.0	5.7	1.1
Solid sheep and goat manure	Range	25 – 48	6.1 – 8.6	1.3 – 2.6	2.3 – 5.2	5.7 – 16	1.1 – 3.5
	Average	30.6	7.8	2.0	4.0	9.9	2.1
Solid pig manure	Range	20 – 30	4-9	0.7-6	1.9-9.2	2.5-7.2	0.5-2.5
	Average	24	6.8	2.4	6.3	4.9	1.4
Solid broiler manure	Range	45 – 85	18 – 40	2 – 15	6.9 – 25	6.7 – 23	2.5 – 6.5
	Average	60	30	7.6	18.5	17.1	4.2
Solid layer manure	Range	22 – 55	13 – 45	5 – 25	8 – 27	6 – 15	1.2 – 6
	Average	40.6	23.6	10.9	16.6	10.7	3.1
Liquid manures [15]							
Pig slurry (no added water)	Range	1.5 – 15.7	2.5 – 10.6	1.3 – 5.5	0.3 – 11.9	2.4 – 10.8	0.2 – 3.0
	Average	7.4	6.5	3.6	3.9	6.8	1.5
Cattle slurry (no added water)	Range	3.4 – 20	2.4 – 7.8	0.2 – 4.4	0.6 – 7.7	1.2 – 9.1	0.6 – 2.7
	Average	9.6	4.9	2.4	2.0	6.2	1.4
Pig bioslurry (no added water)	Range	1.2 – 12.9	2.5 – 10.6	1.6 – 6.9	0.3 – 11.9	2.4 – 10.8	0.2 – 3.0
	Average	6.1	6.5	4.0	3.9	6.8	1.5
Cattle bioslurry (no added water)	Range	2.8 – 16.5	2.4 – 7.8	0.3 – 5.1	0.6 – 7.7	1.2 – 9.1	0.6 – 2.7
	Average	7.9	4.9	2.8	2.0	6.2	1.4

The manure application dose depends on the crop requirements and on the available amounts of nutrients (manure quantity times its nutrient contents). Table 12 gives an impression of possible total contents of some commonly used organic fertilizers. Bioslurry is more homogenous, compared to raw slurry, with an improved N-P balance. Digestate contains more inorganic nitrogen, which is more accessible to plants, than untreated slurry.

Table 12 illustrates the very large ranges in nutrient levels for every type of manure. This suggests that a chemical analysis of every batch of manure is essential for the correct calculation of the required amount per hectare. Averages are indicative only.

7.3 Sampling of manure

Sampling and laboratory analysis of the nutrient content is the only reliable method to know the fertilizing value of the organic fertilizer. Because the nutrient content, particularly nitrogen, of manure can change during storage, sampling and analysis should be performed as close to the time of application as possible. Although sampling manure is often easier at the time of application, the analysis results of these samples can only be used retrospectively e.g. to calculate a second fertilizer application [25]. Therefore this manual only describes the methods to take samples from storages.

Proper sampling is the most important factor affecting the accuracy of manure analysis. Since a very small amount of material is sent to a laboratory for analysis, it is essential that the sample collected is representative of the average composition of the manure being applied. Due to the difference in consistency the method for sampling solid manure differs from that for liquid manure. Some labs provide containers, labels and submission forms, and they may cover the shipping costs depending on the number of samples submitted. Only use plastic buckets for the collection and mixing of samples because galvanized steel containers can interfere with analysis results. Better not use glass containers for either sampling or shipping due to the risk of breakage and subsequent injury and sample loss.

Sampling solid manure (and compost)

The nutrient content of manure stockpiles will vary spatially as manure is piled and mixed with bedding, spilled feed and soil. Manure samples should be collected and thoroughly mixed before a representative composite sample of about 0.5 kg is selected for analysis. Multiple samples may be required to represent the variability of a large quantity of material.

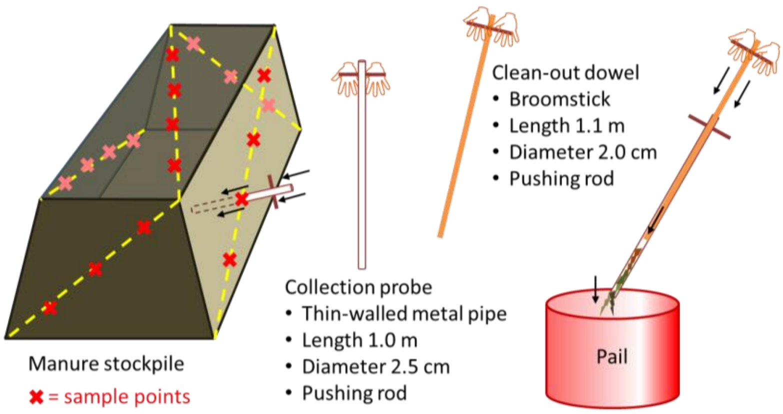

Figure 35. Method and equipment for sampling manure and compost stockpiles [25].

For sampling you need:

- A wheelbarrow or 20 l. pail.
- A pitchfork or sampling probe (Figure 35).
- A plastic sheet (or waterproof floor) to mix on.
- Two (or more) large plastic re-sealable freezer bags.

Collection procedure:

The following procedure should be repeated for each composite sample collected.

Step 1. Select 10 to 20 widely dispersed sampling points on the entire pile according to the diagonals as depicted in Figure 35. Fewer samples may be needed for (more homogenous) compost piles.

- Select sample points that represent the average moisture content of the material.

Step 2. Remove the top crust layer from each of the sample points.

Step 3. Collect samples using a pitchfork, spade or manure collection probe.

- Avoid sampling the weathered exterior layer (outer foot) of the pile and large chunks of bedding.
- Samples should be collected to a depth of at least 45 centimetres into the pile.

Step 4. Collect three to five sub-samples from each sample point and place them into a pail.

Step 5. Each time the pail is two-thirds full, thoroughly mix the collected material, then remove one or two shovelfuls and transfer them to the area (e.g. plastic sheet) designated for mixing.

- To prevent evaporation and volatilization, the collected samples should be stored in a cool location until sampling is complete.

Step 6. Continue collecting samples until all selected points have been sampled.

Preparing a composite sample for analysis

Step a. Combine all the solid manure samples from the pail and mix thoroughly.

Step b. Divide the well mixed manure into four portions (Figure 36).

Step c. Discard two of the four portions.

Step d. Combine the remaining two portions and mix.

Step e. Repeat steps b, c and d until the remaining volume of material is small enough for analysis, approximately 0.5 kilogram.

Step f. The well mixed sub-sample should be placed in a plastic bag filled approximately one-half to two-thirds full.

Step g. Squeeze the excess air out of the bag, close and seal airtight. Samples should be double-bagged to prevent leaking. Label the bag(s) with date, time, farm name and manure type.

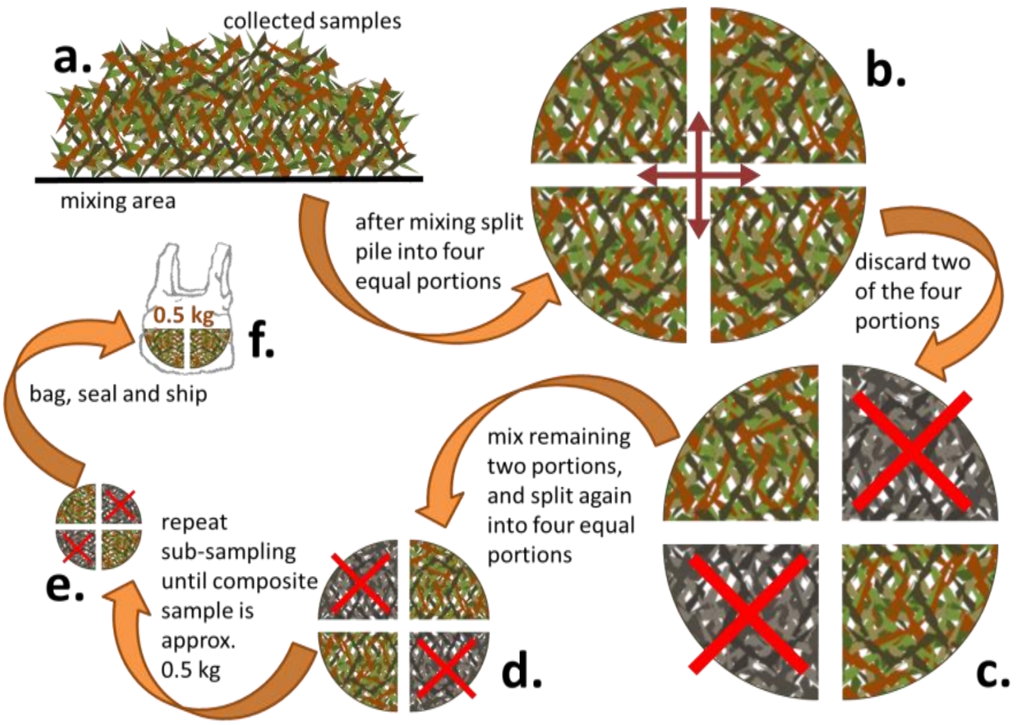

Figure 36. Method to compile a composite sub-sample of manure and compost stockpiles [25].

Sampling liquid manure

Sampling from a liquid manure storage area is not as accurate as sampling during application, and it can be dangerous. The nutrient composition of liquid manure will vary spatially in a storage structure due to solids settling over time. If this spatial variability is not addressed, test results will not reflect the nutrient content of the manure applied. Ideally, liquid manure should be thoroughly mixed for two to four hours before collecting a composite sample. Agitation of the storage mixes the different layers and re-suspends the nutrient-rich sludge layer.

If the liquid manure is well mixed, a single composite sample may be collected and will reflect the average nutrient content of the manure in the storage. If mixing is not performed, a sample should be collected from each depth of the storage profile to build a composite sample that reflects differences in nutrient content.

Liquid manure storage facilities present several hazards to personal safety. Gases such as hydrogen sulphide (H_2S) and ammonia (NH_3) can cause symptoms ranging from headaches and eye irritation to death depending on the length of exposure and gas concentration.
Never enter an enclosed area that contains manure without wearing proper respiratory equipment.

The most convenient time to sample manure is when it is being pumped from the storage for application.

For sampling you need

- One 20 litre plastic pail.
- A manure-sampling device (Figure 37):
  a. composite sampling probe; can be used with either a rope and ball to plug the bottom end, or the hand to airlock the top end;
  b. pole-and-cup device;
  c. bucket and rope.
- One clean one-litre plastic bottle with a screw on lid.
- Two (or more) large plastic re-sealable freezer bags.

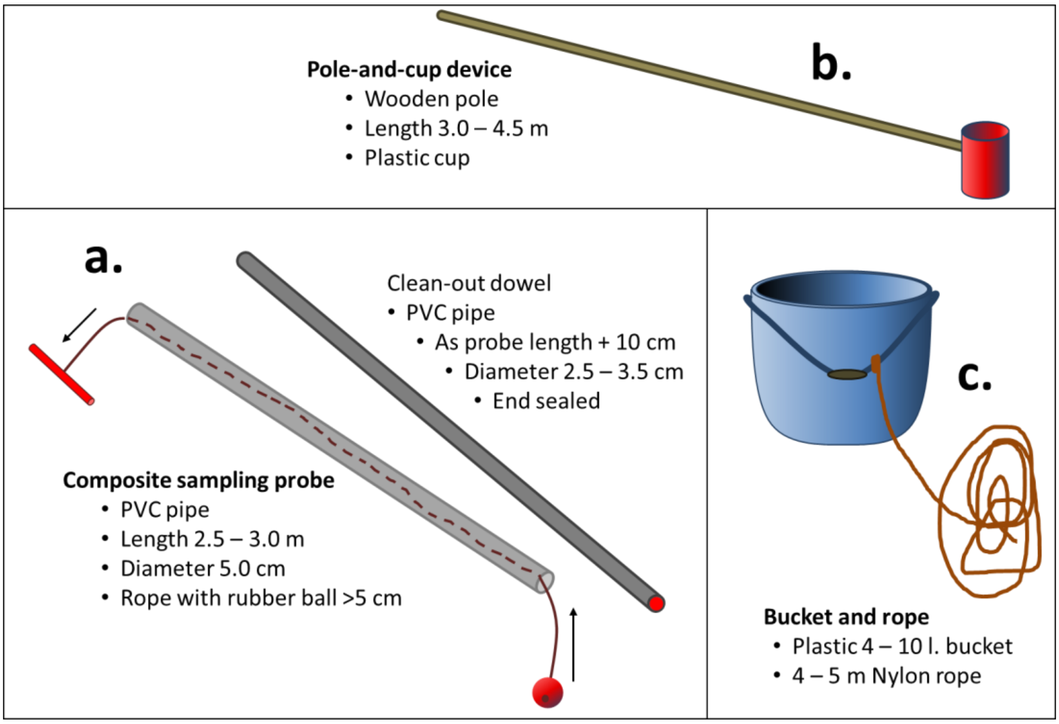

Figure 37. Sampling devices for liquid manure [25].

Collection procedure:

Step 1. To avoid debris or scum in the subsample, brush away floating debris or scum from the collection area.

- *Sampling with composite probe*
  Extend the pipe into the storage about 2 meters away from the edge of the storage. Once the pipe reaches the bottom, seal off the pipe by using either a ball plug or by covering the top of the pipe with your hand (to create an air lock).
  Withdraw the pipe from the storage and pour the manure into the collection pail. Move around the storage and collect 8 to 12 samples from various locations around the perimeter of the storage.

- *Sampling with pole and cup*
  Dip the cup about 2 meters from the edge into the storage and take samples from 8 to 12 different locations near the top, middle and bottom of the storage. In an unagitated lagoon, this method is less accurate than the composite-probe method. Samples may be collected either in one composite pail or in a pail for each sampling depth.
- *Sampling with bucket*
  Throw the bucket out to the middle of the storage while holding on to the rope. Begin pulling the bucket back as soon as it breaks the surface of the liquid, pulling it through the top 30 cm. Raise the bucket above the surface before it strikes the bank. Empty the bucket and repeat this procedure at 4 to 6 locations that are evenly spaced around the perimeter of the storage. Even in an agitated storage facility, this method is the least accurate.

Step 2. Thoroughly mix the composite sample collected.

Step 3. Withdraw a sub-sample from the pail and put it into a plastic bottle, ensuring that the bottle is no more than two thirds full (to allow for gas expansion), and secure the lid to prevent leakage.

Step 4. Label the bottle (date, time, farm name, manure type, contact information) and seal in two plastic bags in case of leakage.

Sample handling, shipping and analysis

Bags and bottles should be kept cool and shipped directly to the lab for processing. If the samples cannot be transported on the day of collection, freeze them until they can be transported to stop nutrient conversion reactions and the build-up of gases.

Samples should spend no more than two days in transit from the farm to the lab. To ensure the samples are not held over weekends or holidays, only collect samples until Wednesday so that shipping can be scheduled.

The following analyses are recommended:

- Moisture content or dry matter content or total solids.
- Total nitrogen (Total Kjeldahl Nitrogen TKN).
- Ammonium nitrogen (NH_4^+-N).
- Total phosphorus (P).
- Total potassium (K).

7.4 Soil Organic Matter

Organic matter keeps soils alive and healthy. Soils low in OM are less fertile and less resilient to drought, and therefore more susceptible to erosion. Because OM decomposes over time, organically bound N will gradually become available to crops. This mineralized N supply reduces the need for additional fertilization (Figure 38). To keep soils healthy and productive it is essential to maintain a OM balance in which the mineralized OM is replenished by newly added OM. Crop residues and organic manure are the most important OM sources to replenish the decomposed soil OM. Synthetic fertilizers do not contain OM!

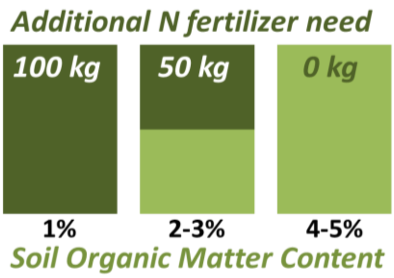

Figure 38. N contribution from soil OM reduces need for additional N fertilizers.

Not replenishing the mineralized OM will result in the crops mining the soil until there is nothing to mine anymore; at which point you have a degraded soil.

Note: this paragraph doesn't apply for peat soils.

7.5 Application

Application rates

As stated in paragraph 7.1 there is not one specific application rate for the diverse manure types on the diverse crops. The desired rate is calculated from crop demand (based on the amount of harvested nutrients) minus soil supply and a possible correction for either over-fertilized or mined soils (based on soil analysis). This results in the initial required nutrient supplementation; divided by the crop available nutrient content per ton fresh matter, based on chemical analysis and the working coefficient (WC) of the used application method and time, results in the required amount to be applied. If this quantity is not available an additional supplementation with synthetic fertilizer can be calculated in the same way. Figure 39 gives an overview of the total calculation. Remember always to start with the available manure products (organic fertilizers). When assessing the amount of harvested nutrients keep in mind that other factors than e.g. N may be limiting maximal crop production e.g. other nutrients, seed quality, water availability, pests and diseases.

Farm-yard manure

FYM can be applied to all soils and almost all crops. In order to make best use of the slowly acting N, FYM should be applied a few weeks before sowing, spread uniformly over the field and immediately plowed into the soil in order to avoid ammonia losses (see paragraph 7.7). Application rates may range from 10 to 40 tons per ha. Smaller amounts are preferably concentrated in plant rows or applied around the base of individual trees or bushes (row and spot application).

Bioslurry

The most tested use of bioslurry is the fertilization of cereal crops, and to a lesser extent of non-cereal crops, such as fruits and vegetables. Whilst bioslurry has the same total nutrient content than undigested slurry, the proportion of total N in the NH_4 can be considerably higher – so the crop available N content can be much greater and at the same time more at risk of loss to the environment if not sub-surface applied or immediately incorporated.

Common application rates are 10 to 20 tons per ha in irrigated areas and 5 tons per ha in dry farming in order to achieve a significant increase in yield. It is sometimes falsely believed that the anaerobic digestion process kills all pathogens, nematodes and viruses present in manure. This particularly concerns domestic biodigesters, which usually only work at relatively low temperatures. For this reason bioslurry should not be applied to fruits and vegetables that are to be consumed fresh.

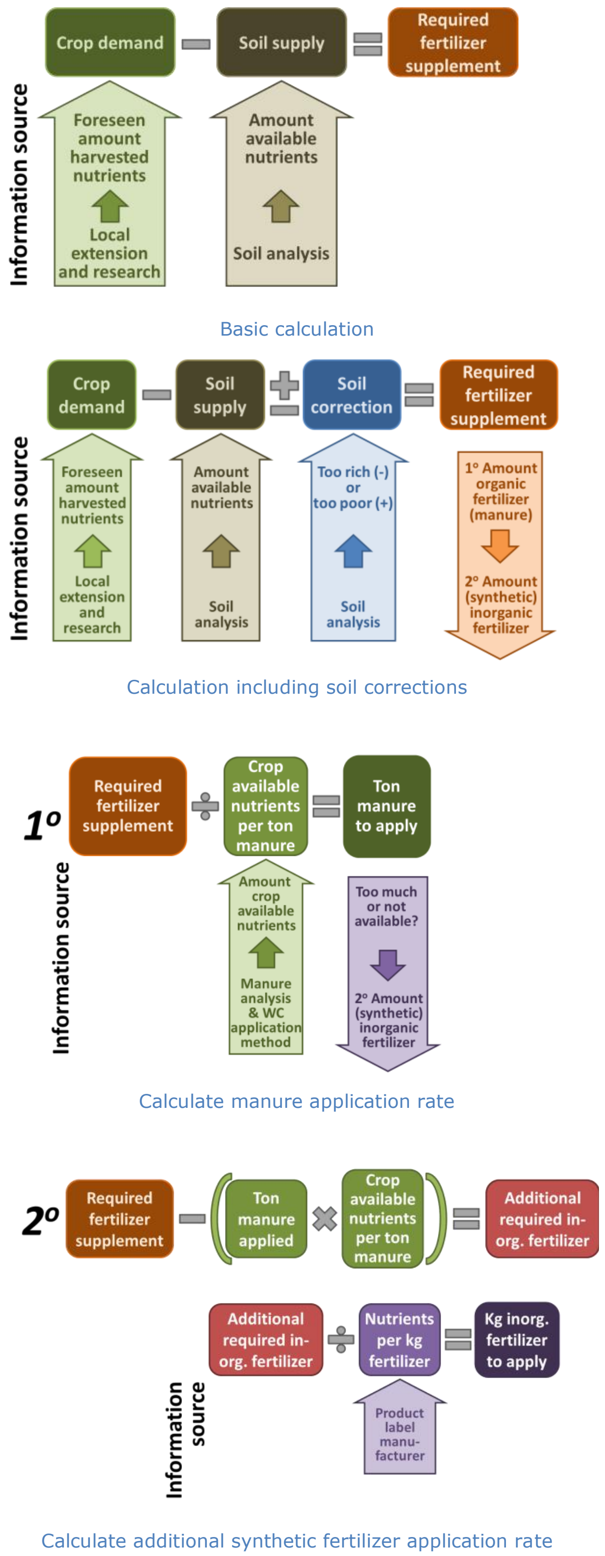

Figure 39. Calculation scheme for organic fertilizers and supplementary inorganic fertilizers.

7.6 Crop response to the use of organic fertilizers

Information on the crop response to using organic fertilizers is very limited and diverse especially under tropical and sub-tropical conditions. Most studies, in which correct methodologies were used, did not show significant differences in yield between the use of bioslurry and farmyard manure. Compared to undigested manure, the direct N availability of bioslurry is high. In the short term, this will lead to a higher N fertilizer value of bioslurry compared to farmyard manure with equal nutrient contents. However, in the long term with annual manure application and the gradual decomposition of OM, the N availability of undigested manure will equal that of bioslurry; in which case no yield differences should be expected. Tables 13 and 14 give a qualitative impression the effects on crop yield found in peer-reviewed sources [13]. Both tables compare the use of bioslurry to the use of other organic fertilizers (Table 13) and to combinations of bioslurry with synthetic fertilizers (Table 14) from different peer-reviewed sources and from different parts of the world.

*Table 13. Comparison of yield with **bioslurry and some organic fertilizers.*** [13]
Yield indications: higher yield (+); lower yield (-); equal yields (=).

	Bioslurry	Slurry	Farm-yard manure	Vermi-compost	Manure Compost
Winter wheat, rye, spelt	=	=	=		
Spring wheat	+	-	-		
Potato	+				-
Cassava leaves	+		-		
Duckweed	-		+		
Sugar cane	-			+	
Sugar cane	+		-		

*Table 14. Comparison of yield between **bioslurry treatment (B) and synthetic fertilizer (SF) treatment.*** [13]
Yield indications: higher yield (+); lower yield (-); equal yields (=).

	Bioslurry	SF (N)	SF (NPK)	Bioslurry + SF
Rice	+		-	
Rice	-		+	
Rice	=		=	
Rice	-			+
Lettuce	+	-		
Sugar cane	-	+		
Kohlrabi	=		=	
Tomato	-		+	

Great care should be taken with data from adaptive research on local farms. In such experiments, the various farm sites are often considered as replicates. To draw reliable conclusions this requires a proper execution of the experiments at all locations and proper statistical techniques for the analysis of the results. Since this is often not the case these kinds of trials should be considered as site-specific demonstrations rather than experiments.

7.7 Application Techniques

The method of application depends on the composition of the manure product, the type of crop, the soil type, and the farm scale. Restrict manure spreading to the beginning of the growing season of the crop; do not apply manure on the land when there is no crop.

All application methods should aim to prevent nutrients (mostly mineral N) from getting lost between the moment of application and the moment of nutrient uptake by crops. Volatilization of ammonia will be reduced when exposure to fresh air is limited in time and contact surface. To minimize open air exposure, manure should be incorporation into the soil (e.g. by harrowing) immediately after spreading or should be injected into the soil directly. Table 15 illustrates the N losses of some farm practices compared to immediate incorporation.

(source: ILRI) (source: ILRI) [source: 7]

Figure 40. Examples of small-scale transportation possibilities and application of liquid manure or urine.

With regard to solid manure application, it is preferable to apply it onto arable land and immediately incorporate it into the soil. Application of solid manure to grassland is not recommended because of the high nitrogen losses, resulting from surface application.

Table 15. Relative NH_4^+-N losses of some field practices as percentage of the total NH_4^+-N. [2]

Application method	Semi-solid manure	Liquid slurry	Lagoon liquid	Dry litter
Injection		5	5	
Broadcast with immediate incorporation	25	25	10	10
Incorporated after 2 days	35	35	20	20
Incorporated after 4 days	60	60	40	35
Incorporated after 7 days or never incorporated	75	75	55	50
Irrigation without incorporation		80	50	

The table clearly illustrates that the longer manure is exposed to open air, the more NH_4^+-N will be lost; and as a consequence the lower the working coefficient (WC) of the total nitrogen. To prevent significant NH_3 emissions (N loss) incorporation within 6 hours after application is recommended.

Liquid manure and slurries can be transported in a tank truck and injected into the soil, both on grassland and arable land, with appropriate equipment. It can also be incorporated immediately after spreading. Or it can be mixed with irrigation water that is subsequently applied to crops. Slurry application with spraying nozzles is not recommended because of high losses of nitrogen.

Incorporating manure spread on the surface by plowing is an efficient means of decreasing ammonia emissions. The manure must be completely buried to achieve the best nutrient efficiencies. Lower efficiencies are obtained with other types of cultivation machinery. Plowing is mainly applicable to solid manures on arable soils but also appropriate for slurries where injection techniques are not possible or unavailable, like in most smallholder situations. Ammonia volatilization starts immediately during and after spreading, so greater reductions in emissions are achieved when incorporation takes place immediately after spreading.

Mechanized application

Manure application techniques to reduce NH_4^+volatilization include equipment for decreasing the surface area (Figure 41) of slurries and covering slurry or solid manure through incorporation into the soil.

Band-spreading

Band-spreaders discharge slurry at or just above ground level through a series of hanging or trailing pipes. The technique is applicable to grass and arable land e.g. for applying slurry between rows of growing crops.

Figure 41. Band spreading is reducing the contact surface of slurry to the open air.

Trailing shoe

This technique is mainly applicable to grassland. Grass leaves and stems are parted by trailing a narrow shoe or foot over the soil surface and slurry is placed in narrow bands on the soil surface. The slurry bands should be covered by the grass canopy so the grass height should be a minimum of 8 cm.

Figure 42. Spring application of slurry on grassland with open-slot injection.

Injection - open slot

This technique is mainly for use on grassland. Different shaped knives or disc coulters are used to cut vertical slots in the soil up to 5 – 6 cm deep into which slurry is placed (Figure 42). Application rate must be adjusted so that excessive amounts of slurry do not spill out of the open slots onto the surface. The technique is not applicable on very stony soil nor on very shallow or compacted soils.

Injection - closed slot

Slurry is fully covered after injection at 5 – 20 cm depth by closing the slots with press wheels or rollers fitted behind the injection tines. Closed-slot injection is more efficient than open-slot in decreasing ammonia emission. The use of closed-slot injection is restricted mainly to arable land because mechanical damage may decrease herbage yields on grassland. Other limitations include soil depth and clay and stone content, slope and the necessary high pulling power requiring a powerful tractor. There is also a greater risk of N losses as nitrous oxide and nitrates in some circumstances. Since closed-slot injection severely cuts through the topsoil, it may not be the most appropriate application method in situations where conservation tillage is propagated.

Practice Case

Bioslurry floating of the hill

Bioslurry from dairy cattle manure after digestion always tends to be very liquid. Liquid bioslurry is often difficult to apply on small-scale farms, especially when the spreading area is not close to the farm. Costa Rican dairy farmer Carlos Gomez and his daughter Karla in the highlands of Turrialba came up with a simple and effective solution. "We let gravity do the job!" They fertilize the hilly pastures using garden hoses; downhill simply by gravity; uphill by pumping it up first. The biogas is used for household cooking and in the small milk processing unit for local cheese production.

7.8 Aquaculture

The use of organic manure to increase biological productivity of fish ponds has become one of the most important management operations in recent years by small-scale fish farmers. Overall, 50 kg of manure produces 1 kg of fish. All studies show positive results, as a proper addition of slurry considerably increases the population of phyto- and zooplankton, thereby increasing the amount of fish feed in the ponds. The effective use of slurry or manure may reduce purchase of pelleted fish feed by up to 50 %. Direct consumption of manure by fish is not very effective with exception for chicken manure.

Over time, phosphate-rich sediment will accumulate on the bottom of fish ponds. This sediment can be recycled to crops as a fertilizer.

Practice Cases

700 pigs and no waste!

The medium-scale Ear Long pig farm in Thailand integrates pork production with crop production and aquaculture. It shows well-thought-out manure management. The 700 pigs are kept on a concrete floor with water flush area. The solid excretions are shovelled out daily. They are either sold or used as organic fertilizer for crops and the ponds with larger fish. The flush water drains into a lagoon with zooplankton. This uses the nutrients in the flush water, thereby improving water quality and providing feed for aquaculture. The water is oxygenated as it overflows to the second, third and fourth lagoons. Finally, the water flows through a shallow pond with buffer plants before being released outside the farm. Oxygenation and buffer plants are additional treatments to clean up the water.

Separating the solid manure and the flush water pays off. Methane emissions are reduced compared to the normal use of mixing dung, urine and flush water. The solid manure is utilized more efficiently compared to liquid manures, while the nutrients in the flush water are recycled as fish feed.

Chicken feed fish

Layer hens are known to produce nutrient-rich manure. Thai poultry and fish farmer Sattha Ponpaipan uses this knowledge effectively. The manure nutrients from his layer hens are completely used to feed his fish. Sattha raises over 20,000 layer hens in four separate houses that are built over ponds with 300,000 fish. Feces drop through metal-slatted battery cages directly into the ponds. Turbines are used to push water with nutrients from under the hen houses to the connecting ponds. The use of chicken manure to feed fish helps Sattha to reduce his spending on pellet fish food by half and to effectively use all the chicken feces. Since the fresh chicken manure is used immediately after excretion, this system avoids losses to the environment. The phosphate-rich sediment in the ponds is regularly removed and used to fertilize nearby trees.

(Photo courtesy: www.thairath.co.th)

7.9 Undesirable manure components

Weed seeds

Weed seeds may end up in manure products through feeding as well as through the use of bedding materials like e.g. dry feed remains or straw. This especially goes for manure from ruminants since they are fed roughage. Some seeds, including those from weeds, survive the intestinal passage and a possible following AD process. In this respect the operating temperature of the digester and the time of digestion play a significant role in reducing the germination potential of seeds [13]. More time at high temperature leads to less seed germination. Time and temperature also are the main factors responsible for reducing the germination power of seeds in composting. The high temperature of the compost-making process may kill many, but not all weed seeds.

Pathogens

Livestock dung can be significantly contaminated with pathogens and cause outbreaks of gastroenteritis related to livestock [13]. This goes for fresh manure as well as stored and or treated manure products. In all cases, direct contact of manure products with especially ready-to-eat crops should be prevented. Storage and treatment may reduce the number of pathogenic organisms, but will never kill them all. Even after 2 months retention, bioslurry may still contain a considerable amount of pathogens such as bacteria, nematodes or viruses, although often in smaller quantities than in undigested manure. This has been shown for the bacteria *Clostridium perfringens, Listeria monocytogenes,* and *Salmonella spp.* This particularly concerns smallholder digesters which usually work at relatively low temperatures (30 – 42 °C). The same applies for the effectiveness of AD on nematodes and viruses.

To prevent water contamination it is recommended not to apply manure within 10 m of open water sources or within 50 m of a water well, nor on steep slopes and waterlogged soils.

Heavy metals

Animal manures can contain heavy metal impurities. In intensive livestock production systems, especially in intensive pig farming, heavy metals are included in the feed as growth promoters. Heavy metals, such as zinc (Zn), lead (Pb), copper (Cu), cadmium (Cd) and arsenic (As), may accumulate with repeated fertilizer applications and thus increase heavy metal concentrations in soils. This might have health implications for the crops as well as the crop consumers (humans and livestock).

Closing Remark

As indicated in the Preface, this training manual cannot possibly cover every local farm situation. However, the manual gives a good overview of the underlying principles of well performed integrated manure management. Knowing that in practice there still are many barriers and bottlenecks for the optimal use of livestock manure, it is good to realize that it is better to apply it in a suboptimal way than not to apply it at all!

For many more information sources go to the library of the Manure Knowledge Kiosk.

8 Information sources

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