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**Struvite production from source separated urine in Nepal:
The Reuse Potential of the Effluent**

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Struvite production from source separated urine in Nepal: The Reuse Potential of the Effluent

Master of Science Thesis
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The findings, interpretations and conclusions expressed in this study do neither necessarily reflect the views of the UNESCO-IHE Institute for Water Education, nor of the individual members of the MSc committee, nor of their respective employers.

DEDICATION

This thesis is dedicated to all who take an avid interest in supporting this research work.

Abstract

Important amounts of nutrients excreted by humans are found in human urine. This provides the motivation for separating urine and recycling it, as fertilizer, back to agricultural land for food production. Urine diverting toilets have been increasingly being promoted in Nepal and more than 500 units have been installed since 2002 (Tuladhar, 2008). However, potential drawbacks to urine handling systems are the risk of ammonia evaporation and the relatively large volumes to be handled. In that situation struvite technology has been established to trap the phosphates in a solid fertilizer. Using the technology could reduce the huge volume of urine and transporting cost. However, struvite production also generates effluent. Struvite effluent reuse has significant potential benefits on both a local and global scale, such as re-circulating plant nutrients like nitrogen and potassium back to agriculture.

This thesis explores the potential reuse of struvite effluent in Siddhipur Nepal. The hypotheses being investigated are that 1) preliminary struvite precipitation prevents clogging during drip fertigation with urine and 2) that drip-fertigation with urine is superior to bucket spreading, because the ammonia volatilization is strongly reduced.

When the nutrients in effluent are beneficially utilized through irrigation some amount of pollutants discharged into our waterways can be reduced.

In this study the small plots for drip irrigation and ammonia volatilization were established. The amount of clogging was based on measurements of head loss in the tank and time of application. The ammonia volatilization measurements were collected in each hour after application.

Boric acid was used to trap the ammonia volatilized in the plots. The method was successfully used to determine that more ammonia volatilized in the plot of the bucket application for up to 2.3 times as compared with drip effluent plot. The maximum loss (11% of the applied N) was measured after application of 45 L of urine per plot while the reference plot with urine in the basin showed average 60% ammonia loss. Virtually no volatilizations were detected (on the first 6hrs) when the urine was applied to the freshly tilled soil. The results also suggest that reuse of struvite effluent through drip irrigation is possible without full clogging (only 30% decrease of flow rate).

The reuse of effluent from a struvite reactor is beneficial in terms of the nutrients that are made available and when applied through drip irrigation the loss of ammonia is reduced. In addition, the reuse of effluent can contribute towards the reduction of importing the commercial fertilizers.

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List of Abbreviations

CEC	Cation exchange capacity
DOC	Dissolved organic carbon
Eawag	Swiss Federal Institute of Environmental Science and Technology
EC	Electrical conductivity
ENPHO	Environment and Public Health Organization
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organisation
NH ₃	Ammonia
NARC	Nepal Agricultural Research Council
NGO	Non-Governmental Organisations
Sandec	Department of water and Sanitation in Developing Countries, Switzerland
SAR	Sodium adsorption ratio
TP	Total phosphorus
TSS	Total suspended solids.
UNESCO	United Nations Education Scientific and Cultural Organization
WHO	World Health Organisation

Glossary

Bittern	Is a viscous semi-clear liquid of a relatively high density (sometimes as high as 1.31) left over after salt has been evaporated from seawater.
Clogging:	Full or partial blocking of drip emitters by silt or other suspended solid matter. As a result of clogging the discharge rate of the emitter is reduced.
Drip irrigation kit:	A package comprising the core components required to install a drip irrigation system. Other components and materials that are readily available at the point of installation are usually not part of the kit unless special qualities of the components are desired.
Drip lateral/line:	The water delivery pipeline or polyethylene pipe that supplies liquid to the emitters from the main lines or sub mains.
EcoSan	Ecological Sanitation
Fertigation:	The application of liquid fertilizer through an irrigation system
Emitter:	A perforated hole in the drip line for discharging the liquid
Newar	Traditional local language in Nepal
pH	A measure of acidity or alkalinity of a liquid. A pH of 7.0 is neutral; a pH less than 7.0 is acidic; a pH greater than 7.0 is alkaline.
Sodicity:	Refers to high exchangeable sodium percentage a relative proportion of Na to Ca and Mg in soil, causing deterioration in soil structure.
Standard Addition:	- A method to determine interferences in chemical analysis of solutions.
UDT	Urine diverting toilet
Urine reuse:	In this study, urine reuse refers to the reuse of urine as a fertilizer in agriculture, either for edible or non-edible crops.

1 INTRODUCTION

1.1 Background

Wastewaters from urban and agricultural sources have great potential for re-use as sources of water, organic matter, nutrients, and soil conditioning agents (Arienzo, et al., 2009). The nutrients in these materials can be reused as fertilizer to plants. The nutrients found in wastewater are highly contributed by human urine which is only less than 1% of the domestic wastewater (Loosdrecht, 2007). The availability and use of wastewater for irrigation have increased as availability of other irrigation water becomes more limited and the commercial fertilizer becomes more expensive. The availability of wastewater as well as the nutrients it may contain makes it an attractive source for irrigation with potential fertilizer cost savings. However huge volume of water used might end up in pollution of the environment and hence urine separating system has been implemented to cater for the problem. One strategy to efficiently utilize these nutrients is to reuse treated effluent for irrigation, and this is widely practiced in many countries. However, this research is not aware of reuse of effluent from the struvite reactor in irrigation. In Nepal the introduction of urine diverting toilets was introduced to counter the situation in that human urine was separated from sanitized matter generated.

Human urine is a natural resource, which is available in all human societies. The reuse of effluent for agricultural irrigation is often viewed as a positive means of recycling nutrients back to soil and plants. Urine effluent has the advantage of being a constant, reliable nutrient source and can reduce the amount of commercial fertilizer to be applied.

Another major benefit of effluent reuse by irrigation is the decrease in wastewater discharges to natural waterways. Rivers and ponds now are merely open sewers for most period of the year in Kathmandu. Substances that can be pollutants when discharged to rivers can be beneficially reused for fertilization of agricultural land. For example, plant nutrients such as nitrogen and phosphorus can stimulate harmful algal blooms in rivers but both are valuable fertilizers for crops.

As water consumption demands have increased together with shortage in rainfall during last few years, the crisis in water supply becomes apparent in many parts of Nepal, including Kathmandu. More efficient use of other resources as valuable as water should therefore be encouraged. An Ecosan technology based on urine diversion has been implemented around Nepal which has the advantages of being water conserving while allowing the valuable nutrients from urine to be recovered.

Separation of urine at the source allows nutrient recycling from a concentrated nutrient solution, thereby reducing the need for advanced nutrient removal from the wastewater (Wilsenach, et al., 2007). Maurer (2006) distinguished between seven main urine-treatment processes: hygienisation, storage, volume reduction (evaporation, freeze-thaw, reverse osmosis), stabilization, acidification, nitrification, P-recovery (struvite formation), N-recovery (ion exchange, ammonia stripping, isobutylaldehyde-diurea precipitation, nutrient removal (anammox) and handling of micro-pollutants, electrodialysis, nanofiltration, ozonation. Their recent review revealed that a wide range of technical options is available to treat collected urine effectively, but that none of these single options can accomplish all seven purposes (Maurer, 2006). The description of urine diverting toilet underlining the opportunity for closing the nutrient loop by treating and reusing the end product safely takes dry solid into the context of ecosan: re-use is within the domain of ecological sanitation (Lind, et al., 2000).

There are other uses for separated urine as well. It can be used to treat green composts, such as straw and corncob, to balance the C/N ratio and to irrigate composts as needed. On the other hand, urine has been found to act as a source for P recovery as struvite. Udert (2003) and Tilley (2008) concluded that the storage of urine is an essential step in recovering struvite, and that by allowing the pH to attain an ideal working range naturally, only magnesium needs to be added to recover a pure struvite product.

One other feasible resource is struvite effluent, which is an emerging means of fertilizing the farms. It is envisaged that the reuse of effluent in individual households in Nepal can contribute towards the reduction in water consumption and wastewater volume discharged into treatment systems. Urine in most cases is considered to be sterile (Schönning, 2004). In addition, urine effluent usually contains essential nutrients for plant growth (Heinonen-Tanski, et al., 2007). Therefore, the effluent may be reused for farm irrigation without treatment. If feasible, this practice would provide a cost-effective solution to conserve water and improve soil nutrients.

This research focused on reusing the effluent that was generated from a struvite reactor. The results showed that struvite effluent could be applied through drip irrigation without clogging, and that it is beneficial to apply fertilizer in a way that will minimize volatilization.

1.1.1 Urine diverting toilets in Nepal

The urine diverting toilet (UDT) pilot project commenced in 2002 to promote the use of UDT as one of the strategies to improve the sanitation standards and health conditions of people living in poorly sanitized area of Siddhipur.

This was done by constructing and demonstrating the proper utilization of ecological sanitation toilets which can help close the nutrient loop, which previously had resulted in the loss of many required nutrients found in urine and faecal matter.

The urine diverting toilet is designed in a way that facilitates the separation of urine and faeces. This is intended to ease and speed up the process of managing the excreta, and to make it safe for recycling purposes. Empowering communities to sanitize the urine and faecal material for use as manure was identified as the best way to close the loop.

Source separation of human urine in Nepal is based on urine diversion dry toilets equipped with two bowls, a front one for the collection of urine and a rear one for faecal material. Thus, the urine is supposed to be collected separately and led through a pipe to a collection drum for urine (Figure 1.1). Urine diversion is based on the fact that urine contains most of the nutrients in domestic wastewater but makes up less than one percent of the total wastewater volume (Loosdrecht, 2007)

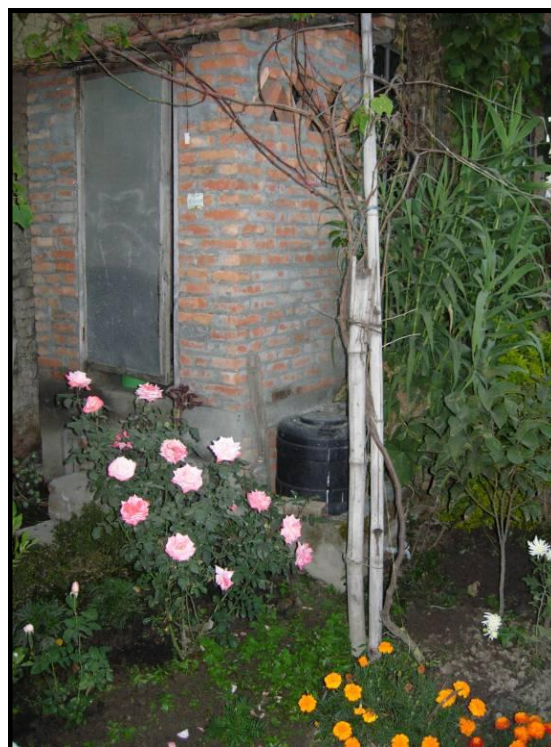


Figure 1.1: Urine separation toilet- Siddhipur

1.1.2 STUN project description

STUN stands for Struvite from Urine in Nepal and is a project that is funded by Eawag Switzerland. The aim of the project is the recovery of phosphorus from human urine in the Kathmandu valley peri-urban area. The project is divided into two phases. The first phase was mainly focused on working on the feasibility study and current sanitation situation, both in terms of cultural and social issues, but also determining the number of EcoSan toilet, the volume of urine produced, and concentration of nutrients. The second phase included two parts: the field operation of the reactor and the usage of the effluent from the struvite reactor. The effluent reuse was studied in this Master's thesis.

Sandec is the Department of Water and Sanitation in Developing Countries. It operates from Dübendorf, Switzerland. Sandec (The Department of Water and Sanitation in Developing Countries) and the Engineering Department (ENG) have been conducting the research on recovery of struvite from stored human urine and have shown that separate collection and treatment of urine could make significant contributions to water pollution control and nutrient recycling.

1.1.3 Problem description of Siddhipur

This research project was conducted in Siddhipur (Kathmandu area) **Figure 1.3** as a case study to investigate the possible reuse of struvite effluent through the drip irrigation and also emission of ammonia from different application.

Siddhipur is a traditional Newar settlement located approximately six kilometers southeast of Kathmandu. It covers an area of 1.9 square kilometers with 6,046 inhabitants in 1,308 households. The settlement is among the settlements in Kathmandu valley where the ecological sanitation has been increasingly adopted as the alternative for providing hygienic sanitation. According to a Wateraid report (Tuladhar, 2008) more than 500 urine diverting Ecosan facilities have been installed since the introduction in 2002. The urine diverting toilet involves the separation of urine at the source of production (NoMix toilet) and it is important to handle this fraction properly.

However, one of the challenges that goes with this development is the reuse of the by-products.

Agriculture is the backbone of Siddhipur and Nepal economy in general. The use of fertilizer is vital and the country is heavily dependent on the prompt arrival of the monsoon for irrigation. Urine and faeces are good nutrients and have been used locally to supplement commercial fertilizer in Nepal.

Between June and August as shown in Figure 1.2, Siddhipur experiences the monsoon rainfall that peaks at 37.3mm. Despite the fact that agriculture needs the nutrients which are particularly in the urine, it will be very difficult to apply the urine in that period continuously. Urine application is not recommended during excessive rains to avoid the leaching of nutrients

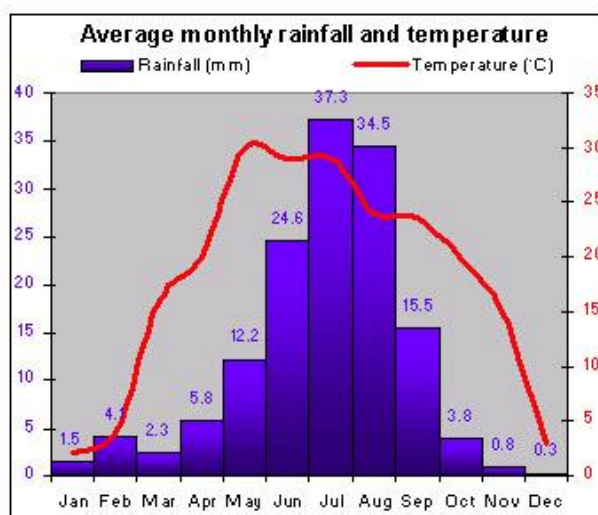


Figure 1.2: Average monthly rainfall and temperature : Kathmandu Nepal (source: 3D world Atlas)

although soil moisture is important for nutrient uptake by the plant. This implies that bigger storage facilities will be required during that time which is economically unbearable to most of Siddhipur dwellers. Realizing these problems the project came up with the management model of urine collection, where a centralized place has been set up for the purpose of processing the urine into struvite. Furthermore, it has been suggested that storing the urine at 20°C is beneficial as most the harmful microorganism will die off in 6 months (Höglund, et al., 2002)

The study site for this research was the farm of Mr. Jiban Maharajan who had already been using urine alone, urine in combination with composted sanitized faeces in his farm. The products of his farm have been sold to Kathmandu. Some people also have come directly to the farm to purchase vegetables due to high yields throughout the year.



Figure 1.3: Nepal, Kathmandu study area

1.1.4 Urine reuse option for Siddhipur

It is obvious that the open space available in densely populated urban areas does not allow *in situ* recirculation of all nutrients in human excreta, even if all land were to be allotted to agricultural use. A balance has to be struck between utilising excreta in the neighbourhood, and transporting it to farms on trucks and bicycles or through sewers (Drangert, 1998).

Reusing is not a new concept in Siddhipur; farmers have been practicing the use of night soil in combination with animal waste, kitchen and other agricultural waste as the main fertilizers in the agricultural fields for decades. However, living condition of this settlement is poor and unhygienic due to inadequate water supply and lack of sanitation facilities. In order to improve sanitary condition, pit latrines were promoted a decade back in a peri-urban settlement. Unfortunately, most of these structures are not functioning due to high water table. Functional pit latrines have also problems like overflow, odor and flies. In addition, most of these centers lack sufficient drainage. Therefore, all the surrounding ponds and dug wells are now extremely polluted due to the seepage from pit latrines and surrounding runoff, which were the major drinking water sources in the past. Realizing those facts, ENPHO selected a few peri-urban centers including Khokana, Lubhu, Imadol and Siddhipur for the demonstration of UD systems (Shrestha, 2006).

As it can be seen from Table 1.1 the predominant reuse practice was to apply it through compost. This practice has its bottlenecks as urine volatilizes during the process.

Table 1.1: Methods of using urine

Methods of using urine	Number of Households
Directly on the field	161
Put in compost	210
Give to others	6
Throw out	86

Source:(Tuladhar, 2008)

Table 1.1 Shows that the traditional practice of using urine is prominent in the area. Bucket spreading of urine is one way they have been using urine, and urine has also been applied on leaves or other parts of the plants and certainly causes foliar burning due to high concentrations of salts when drying. The throwing out practice is also not advisable due to the risk of ammonia loss through gaseous volatilizations of ammonia (Johansson, 2001) and the hygiene risk.

The Table 1.2 below shows the measured values of nutrients in the urine as it has been applied in Nepal as alternative for commercial fertilizers.

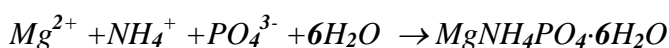
Table 1.2: Composition of urine from storage vessel

Element	N	P	K
Concentration (gL ⁻¹)	9.12	0.26	0.85

Source (Shrestha, 2006)

As the number of ecosan units kept on increasing the management practice and awareness training have to be taken into consideration. The established urine separation toilets will result in an increased amount of volume to be processed and transport implication of urine solution (Gantenbein, 2008). An alternative in this research was to look at the effluent generated hence utilizing the amount of urine solution from precipitation techniques i.e. through interception a significant proportion of phosphorus by phosphates precipitation.

The recovery of nutrients using a crystallization technique would provide a value added product with less cost. This is particularly true when considering the recovered product struvite and its effluent utilization. Struvite is chemically known as magnesium ammonium phosphate hexahydrate.



Production of struvite incorporates a chemical reaction among magnesium, ammonium and phosphate ions and combines six molecules of water. Struvite may be utilized as a valuable source of slow release fertilizer due to its solubility characteristics (Nelson, et al., 2003). However, the treatment of separated urine has not yet been developed into marketable processes (Wilsenach, 2005).

In the literature, several papers addressed the recovery of phosphate as struvite from industrial and domestic wastewater (CEEP, 2004, Jaffer, et al., 2002, Ronteltap, 2007). The precipitation of struvite may present some problems in wastewater treatment plants causing deposits in pipe walls (Loewenthal, 1994). However, struvite has a potential use as a fertilizer. It has been shown to be a highly effective source of nitrogen, magnesium and phosphorus for plants and can be used as a slow release fertilizer at high application rates without damaging plant roots (Gaterell M.R., 2000).

It is envisaged that many of the problems connected with urine separation could be met by transforming the nutrients in the urine into solid minerals. Handling and storage could be substantially improved, the volume would be dramatically reduced compared with liquid urine, loss of nitrogen into the atmosphere would be eliminated, a high level of hygiene could be maintained and spreading on arable land could be much more flexible in terms of time and dosage. This study also provides invaluable basic information on examining precipitation in drip piping for irrigation.

1.2 Goals and objectives

Currently in Siddhipur, there is an ongoing project that is investigating the recovery of struvite from urine. One of the main challenges of the large-scale production of struvite is the disposal and treatment of effluent that is generated. After struvite is recovered from urine, an almost equal amount of effluent remains.

Effluent in this thesis refers to the liquid remaining after the processing of struvite from urine.

Influent shall refer to urine that is collected from urine-diverting toilets, before it is processed into struvite.

Effluent has an elevated pH (average 8.5), and average of 2922 mg/L of ammonia and almost no remaining phosphorus (Table 4.4). Therefore, the potential that minerals will continue to precipitate from the effluent is low. However, the high concentration of ammonia means that a great deal of nutritive value could still be recovered and used beneficially.

The goal of the study was to determine the effects of using effluent from struvite production in drip irrigation.

The hypotheses of this study are:

Hypothesis 1: Effluent from struvite production, can be used without clogging in drip irrigation systems.

Specifically,

- Effluent will clog less than urine (untreated) in drip lines
- Dilution of effluent will decrease the incidence of clogging in drip lines

Hypothesis 2: Ammonia volatilization is greater from urine that is applied with a bucket than when it is applied with drip irrigation.

In order to prove these hypotheses two sets of experiments were conducted in Siddhipur where urine has been collected from urine separation toilets at the residential household level.

To prove Hypothesis 1, five drip kits (see glossary) were installed on agricultural fields. Five different liquids, effluent, influent, diluted effluent, diluted influent, water were used and the head loss from each tank was measured over a period of two months.

To prove Hypothesis 2, four plots on agricultural land were used for spreading urine and measuring the amount of ammonia that volatilised. One plot was used for the spreading of urine with a bucket (traditional method), one plot was used for the spreading of effluent with a drip kit, one plot was used to quantify the ammonia volatilization from a basin (reference field), and one plot was used as a control plot to measure the background concentration of ammonia.

1.3 Scope of the research

This master's research addresses the reuse potential of struvite effluent through drip irrigation. It looked at both the clogging rate in drip lines and the ammonia volatilization of effluent. The results were compared to other urine-derived liquids.

The scope of this research excludes greywater and faecal waste management. The thesis does not cover the operation of struvite reactor nor the hygienic part of urine. Additionally the logistic of transporting urine from the household to the reactor is also not covered.

2 LITERATURE OVERVIEW

2.1 Use of Urine

One strategy to increase the recycling of nutrients from wastewater to agriculture is to handle urine separately and use it as a fertilizer in agriculture. The nutrients from source-separated human urine has the potential to replace the import or production of mineral fertilizers. Potential drawbacks to urine handling systems are the risk of ammonia evaporation and the relatively large volumes to be handled. The amount of urine solution could be reduced by using techniques like struvite, but it captures only a negligible amount of the ammonia in urine.

Urine reuse has been applied around the world in many countries. Reusing urine as a source of phosphorus fertilizer will preserve the world’s limited geological sources of phosphorus. The **Figure 2.1** below shows the composition of urine of all the sources of nutrients in household wastewater, human urine is the largest contributor. Urine contains approximately 85% of all nitrogen, 50% of phosphorus and 70% of potassium found in household wastewater.

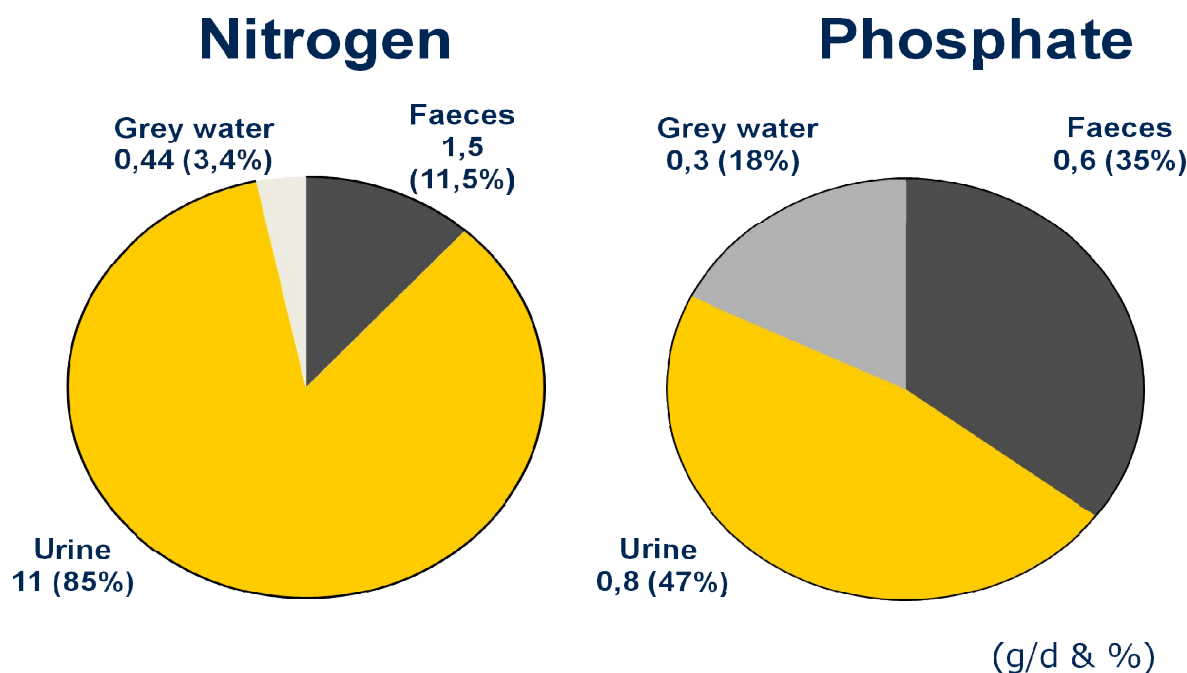


Figure 2.1: Sources of nutrients in wastewater

Source:(Loosdrecht, 2007)

In this situation, the key drivers for using urine-diverting toilets are based on excess nutrient loads. Additionally urine is sterile unless it gets contaminated through handling during reuse.

Urine fertilization used to be rare. However, it has gained attention in some areas as farmers embrace organic production methods and try to reduce use of synthetic fertilizers.

2.2 Phosphorus and its role

Phosphorus is a major limiting plant nutrient which is available in large concentrations in urine. Because phosphorus is highly reactive, it does not naturally occur as a free element, but is instead bound in phosphates. Phosphates typically occur in inorganic rocks(Ganrot, et al., 2007). Most phosphorus is obtained from mining phosphate rock. Crude phosphate is now used in organic

farming, whereas chemically treated forms such as superphosphate, triple superphosphate, or ammonium phosphates are used in non-organic farming.

Perhaps even more importantly dissolved phosphorous is present in urine as orthophosphate PO_4^{3-} and precipitates out of solution in urine mainly in the form of struvite ($\text{MgNH}_4\text{PO}_4 \cdot 6 \text{H}_2\text{O}$) and hydroxylapatite ($\text{Ca}_{10}(\text{PO}_4)_6(\text{OH})_2$) (Udert, 2003) Although these solid forms of phosphorous can break down over time and become bio-available, the form most directly available to plants is the phosphate ion in solution.

As farmers and gardeners know, phosphorus is one of the three major nutrients required for plant growth: nitrogen (N), phosphorous (P) and potassium (K). Fertilizers are mostly labelled for the amount of N-P-K they contain.

In the views of the current practice, especially in industrialized nations which are to remove or destroy the phosphorus and nitrogen in wastewater by restricting it from entering surface water, addressing these problems in that perspective reduces the pollution in receiving waters, but it does not stop the depletion of finite resource.

In the literature, estimates before depletion of available phosphorus resources is expected to be 100 years (UNEP, 2001). This date seems conveniently far enough in the future but immediate action is required to combat the situation.

Interaction with irrigation: Irrigation with effluent could increase the amount of available phosphorus in soil for plant uptake. However, potential problems could occur from excess P loading when drainage occurs, which could contaminate groundwater and may cause eutrophication through erosion of P-rich topsoil and a discharge of dissolved P in runoff to surface water bodies. With respect to soil nutrients, however Das and Kumar (2008) state “Irrigation with effluents containing phosphorus in excess of plant requirements is beneficial to phosphorus availability and soil’s phosphorus in long term”.

The type and the level of nutrients in the soil were determined and used as the baseline for ongoing research on the reuse of effluent, in relationship to micro-irrigation and ammonia volatilization.

2.3 Struvite

Nutrients recovered from urine might be a viable source for the gradual replacement of commercial fertilizers and may help to ultimately close the phosphorus loop. Struvite precipitation holds great potential for phosphate recovery but only a small fraction of the nitrogen can be recovered this way (Jaffer, Clark, Pearce and Parsons, 2002). A major mechanism proposed in this topic is the reuse of effluent that once would have been discarded into the environment after precipitation. The reuse of effluent for agricultural irrigation should have a positive effect due to its high amount of nitrogen. The advantage of using the effluent is its supposed low content of particles and its low risk of precipitation.

Clearly, the widespread application of struvite precipitation will provide a phosphorus resource that could be processed economically in the future. Since phosphorus is a non-renewable resource, recovering phosphorus from human waste (urine) is a significant breakthrough technology. The utilization of the effluent with drip irrigation is an important additional benefit, because it allows reusing other nutrients such as nitrogen, potassium and sulfur as well.

2.4 Struvite Precipitation

According to J.P. Klein and R. David, (1995) Precipitation (also named reaction crystallization) is an area for which aspects of crystallization as well as reaction engineering are very important. Struvite is a chemical compound, magnesium ammonium phosphate, which can be formed by the controlled addition of magnesium to a waste stream that contains nitrogen in the form of ammonia and phosphorous in the effluent from a manure treatment system allows reduced land application field area (Marti, et al., 2008). Second, struvite has a commercial value, either as a pure high-phosphorus fertilizer, or as a supplement to compost or other fertilizers.

Historically, much of the literature and concern with struvite precipitation has been in determining how to avoid struvite scale from forming in the piping and equipment of wastewater treatment plants and agricultural waste systems (Wrigley, et al., 1992). As concern grows over the management of nutrients (especially phosphorous) in wastewater and manure, research on and application of controlled struvite precipitation has increased around the world (Michael S. Massey, 2007). The Netherlands, Australia and Japan are among the first countries where a significant amount of research on struvite precipitation has been completed (de-Bashan and Bashan, 2004). Proprietary struvite recovery processes for municipal and industrial wastewaters have been developed both in the Netherlands and Japan (Wilsenach, 2005). A non-proprietary struvite recovery process is treating veal manure at a full-scale plant in the Netherlands. Work in the United States has been largely research on pilot studies using hog manure.

2.5 Use of struvite and struvite reactor effluent

A laboratory study of struvite precipitation noted that a major advantage of this process is that the struvite produced is a valuable slow-release fertilizer. Bridger *et al.* (1962) and Rothbaum and Rohde (1976) as cited by (Wrigley, Webb and Venkitachalm, 1992) found that struvite improved plant growth compared with conventional fertilizers for grasses, fruit and high-value crops such as strawberries.

Struvite has many uses. The most obvious is as a raw material for the fertilizer industry (Gaterell M.R., 2000).

If cheap production methods are developed, the phosphate recovered industrially from struvite could be used in detergents, cosmetics, and animal feed, all of which use phosphates (Gaterell M.R., 2000).

While struvite has many potential uses as fertilizer, as yet, none have been proven commercially profitable (Shu, et al., 2006). The most promising application is as a slow-release fertilizer that can be applied in a single high dose without damage to growing plants. The plants suggested in many books are ornamentals, vegetables, forest out-plantings, turf, orchard trees, and potted plants. This fertilizer might have low leach rates and slowly release nutrients during the growing

There are numerous publications on struvite precipitation but we did not find any research on struvite effluent reuse from human urine. The process of struvite reactor as applied in Siddhipur is as shown in Figure 2.2.

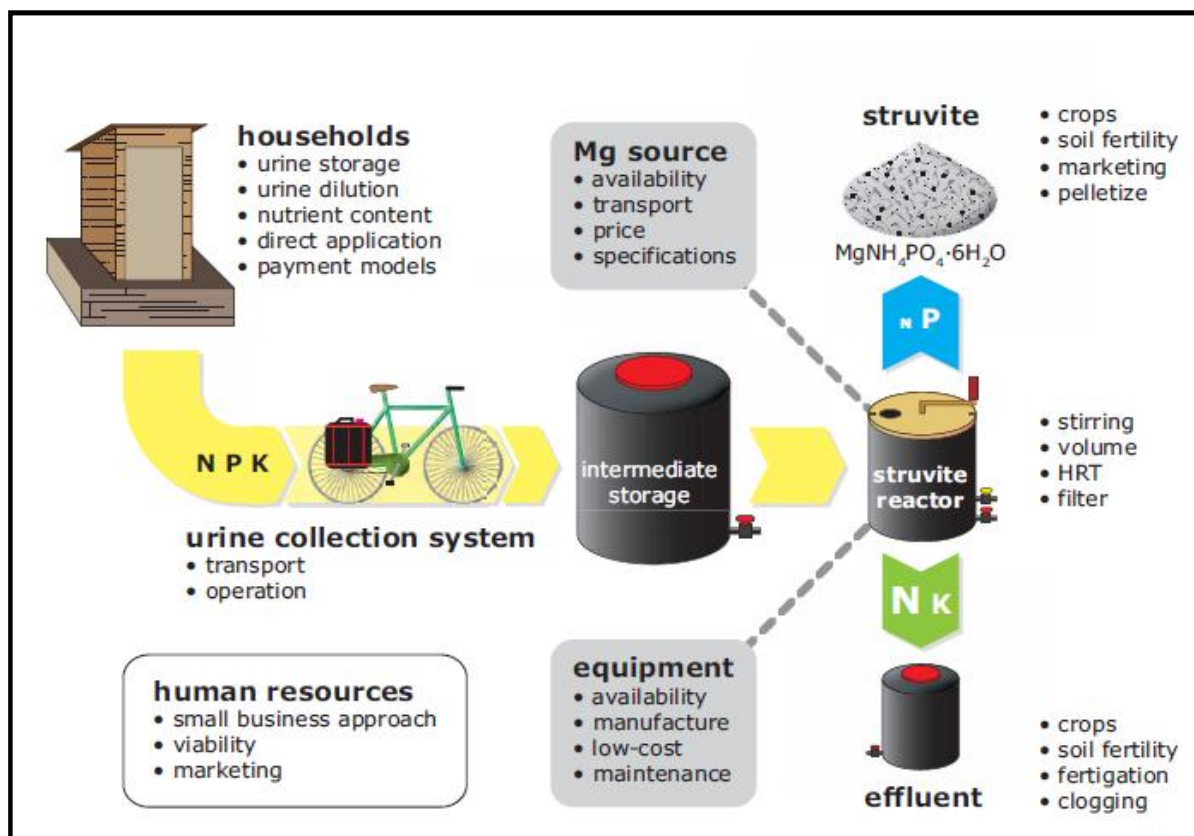


Figure 2.2: Struvite production process- Siddhipur

Source:(Etter, 2008)

2.6 Fertigation

This research examines the potential of liquid effluent from the struvite reactor to be used as fertilizer. While phosphate is nearly completely recovered as struvite during precipitation, the effluent still contains all of the potassium and more than 95% of the ammonium.

Currently there is no known information about using effluent from struvite reactor. The information obtained from this study will provide an efficient method of fertilizer delivery virtually free of cultural constraints that characterize other production systems. It is envisaged that the proper management of drip irrigation lines can reduce overall, current fertilizer application rates and minimize adverse environmental impact in agriculture sector.

Bhat et al. (2007) are describing the advantages of drip fertigation. In general, drip fertigation is about applying the nutrients more directly to the wetted root volume, where the active roots are concentrated. This increases the efficiency in the application of the fertilizer, which allows reducing the amount of applied fertilizer. This not only reduces the amount of fertilizer required, but also lessens the potential of groundwater pollution caused by the fertilizer leaching. Fertigation allows adapting the amount and concentration of the applied nutrients in order to meet the actual nutritional requirement of the crop throughout the growing season.

Other advantages of the fertigation are: (1) the saving of energy and labor, (2) the flexibility of the moment of the application (nutrients can be applied to the soil when crop or soil conditions would otherwise prohibit entry into the field with conventional equipment), (3) convenient use of

compound and ready-mix nutrient solutions containing also small concentrations of micronutrients which are otherwise very difficult to apply accurately to the soil, and (4) the supply of nutrients can be more carefully regulated and monitored. When fertigation is applied through the drip irrigation system, crop foliage can be kept dry thus avoiding leaf burn and delaying the development of plant pathogens.

Clogging

Although fertigation has numerous potential advantages, there are also some possible bottlenecks one of them is clogging. This is specifically critical for drip systems that must be kept free from suspended solids and microorganisms that plug the small orifices in the emitters. Water sources for irrigation that have high contents of calcium, magnesium and bicarbonates (hard waters) are undesirable. The interaction of these waters with fertilizers can cause diverse problems, such as formation of precipitates in the fertilization tank and clogging of the drippers and filters (Schwankl, 2001). In waters with high calcium content and bicarbonates, use of sulphate fertilizers causes the precipitation of CaSO_4 obstructing drippers and filters. The use of urea induces the precipitation of CaCO_3 because the urea increases pH. Clogging is also the main problem of fertigation with phosphorus fertilizers (Flynn, 2001). The presence of high concentrations of calcium and magnesium and high pH values lead to the precipitation of calcium and magnesium phosphates. Alternative reuse of recycled waters is particularly susceptible to precipitation due to its high bicarbonate and organic matter content. The resultant precipitates are deposited on pipe walls and in orifices of drippers and can completely plug the irrigation system. At the same time, P supply to the roots is impaired (Pessarakli, 2004).

The use of fertilizers with acid reaction partially corrects the clogging problem. However, acid fertilizers cause corrosion of the metallic components of the irrigation system and damage the cement and asbestos pipes. Therefore, periodic injection of acid in the fertigation system is recommended in order to dissolve the precipitates and to unclog the drippers. The following acids can be used phosphoric, nitric, sulfuric and hydrochloric, HCl is regularly used due to its low cost. Acid injection through the system will also remove bacteria, algae and slime (de Kreij, et al., 2003, Schwankl, 2001).

Nitrogen

Nitrogen is the plant nutrient most often injected into drip fertigation systems. The benefits include reduction in potential leaching by applying the nitrogen as the plant require it, thus excess is not available to be leached in the event of a heavy rainfall. Nitrogen can be applied in several forms. Urea and ammonium nitrate, however, are the most desirable sources since they produce the least risk of plugging (Zotarelli, et al., 2008). Anhydrous or aqua ammonia is not recommended for use in micro irrigation systems because it will raise pH, and irrigation water with significant amounts of bicarbonate will precipitate calcium, magnesium, and phosphorus if pH is elevated (Schwankl, 2001). Ammonium sulfate and calcium nitrate can be solubilized but they may cause plugging problems. If calcium or magnesium levels are high, ammonium phosphate may cause precipitates to form, which can plug emitters (Quiñones, et al., 2007). Nitrogen can contribute to microbial growth if it is applied continuously.

Phosphorus

Phosphorus fertilizer injection may cause emitter plugging. This occurs most often due to interaction between the fertilizer and the irrigation water. Phosphorus is also not very mobile in

the soil and is less likely to be lost when applied conventionally. The application of ammonium polyphosphate fertilizers to water which is high in calcium will almost always result in the formation of precipitants which can plug the emitters and which is very stable and not easily dissolved. For these reasons the injection of phosphorous into micro irrigation systems is often not recommended (Hebbar, et al., 2004)

Phosphorus and calcium, when in solution together, may form di- and tricalcium phosphates which are insoluble. Similarly, phosphorus and magnesium can form magnesium phosphates which are also insoluble and plug irrigation system emitters (Schwankl, 2001). Plants generally need phosphorus early, so it is important that the element, if deficient in the soil, be applied at or before planting. If the plant shows phosphorus deficiency symptoms during the growing season, injection of phosphorus into the irrigation water allows for late stage correction.

Potassium

Injection of potassium through micro irrigation systems has been very successful. The problem most often associated with potassium injection is solid precipitants that form in the mixing tank when potassium is mixed with other fertilizers. The potassium sources most often used in micro irrigation systems are potassium chloride (KCl) and potassium nitrate (KNO₃). As previously indicated potassium phosphates should not be injected into drip irrigation systems. Potassium sulfate is not very soluble and may not dissolve in the irrigation water (Schwankl, 2001).

Fertigation solubility

A variety of fertilizers can be injected into drip fertigation systems. Soluble NPK fertilizers are available in the markets which are appropriate for fertigation but the price might be in certain cases the main constraint.

All fertilizer sources must be highly soluble. Table 2.1 shows the solubility of common commercial fertilizers. It is difficult or impossible to unclog drip fertigation tubing once you have clogged it with insoluble fertilizers, algae, or sand. However, most of the common P and K fertilizers are not convenient for fertigation due to their low solubility. This is particularly the case with the P fertilizers.

Table 2.1: Solubility of common fertilizers in water

Material	Temp °C	Solubility (gm/100mL)
Nitrogen Fertilizers		
Ammonium Nitrate	0	18.3
Ammonium Polysulfide		high
Ammonium Sulfate	0	70.6
Ammonium Thiosulfate		v. high
Calcium Nitrate	17	121.2
Urea		100
Urea Sulfuric Acid		high

Source: (Boman, 2002)

Commercial standard P-fertilizers may also precipitate in the irrigation lines in reaction with ions in the irrigation water such as Ca or Mg. Therefore, when choosing the P fertilizer for fertigation, besides solubility, care must be taken to avoid P-Ca and P-Mg precipitation in the drip lines and emitters (Ajdayr, et al., 2007). Different sources of fertilizers, including P fertilizers, have different effects on irrigation water and soil pH. High pH values in the irrigation water are undesirable. Calcium and Magnesium carbonate and orthophosphate precipitation may occur in the drip lines and the emitters.

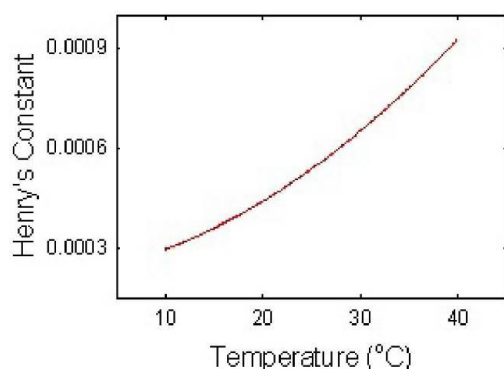
2.7 Ammonia volatilization overview

It is primarily the atmospheric, ecological reasons, along with the economic ones, that compel researchers to deal with the NH_3 volatilization in agriculture and reduce them adequately. From an agricultural viewpoint, NH_3 volatilization is a direct loss to the farmer. Ammonia losses are not only losses of an expensive plant nutrient, but they also damage terrestrial and aquatic ecosystems. NH_3 volatilization can have negative effects on the environment and human health i.e. Aerosol forming and groundwater pollution through leaching.

Ammonia (NH_3) and ammonium (NH_4^+) are important atmospheric components (Rodhe, et al., 2004). Gaseous NH_3 originates in both natural and agricultural systems but the largest fraction comes from livestock waste, fertilizers, and other sources. Once in the atmosphere, NH_3 is the dominant alkaline gas and is the principal agent for neutralizing airborne acids, such as sulfuric, nitric and hydrochloric acid (Thompson and Meisinger, 2005).

As pointed in the objectives of this study, almost all ammonia that enters the struvite reactor comes out in the effluent. When ammonia comes in contact with soil the dissolved NH_4^+ which has a positive charge, can be attracted to the negative charges present in clays and organic matter, becoming exchangeable NH_4^+ . As a result, soils with a large cation exchange capacity (CEC) adsorb more NH_4^+ and show smaller NH_3 losses than soils with a small CEC (Kissel, 2005). Also, any rain, irrigation after application, or tillage that moves the ammoniacal N into the soil usually enhances adsorption of NH_4^+ and reduces NH_3 losses.

For NH_3 to be lost as a gas, some of the NH_3 dissolved in the soil solution has to be converted to gaseous NH_3 , a process that is controlled by Henry's Law constant. Henry's constant describes the proportion of NH_3 that is in the soil air compared to the adjacent soil solution. The proportion in the soil air increases approximately 3-fold as the temperature rises from 10 to 40°C (Figure 2.3). In summary, NH_3 volatilization increases when soil temperature rises because 1) the conversion of organic N to NH_4^+ increases, 2) the proportion of total ammoniacal N as NH_3 increases, and 3) the proportion of NH_3 in the soil air increases.



C_{air} = concentration in the air (NH_3)

C_{urine} = Concentration in the urine (NH_3)

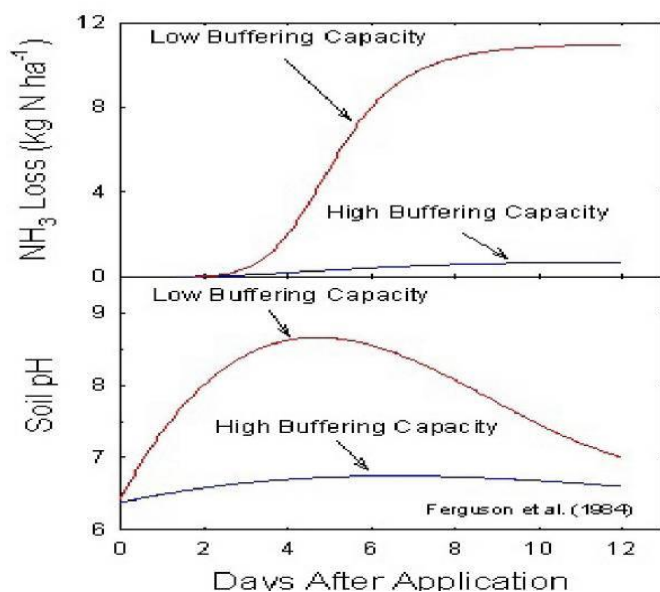
H = Henry's constant

$$C_{\text{air}} = H * C_{\text{urine}}$$

Figure 2.3: Effect of temperature on Henry's constant for

Once NH_3 is in gaseous form, it diffuses out of the soil at a rate that is proportional to the difference in gaseous NH_3 concentration between the soil air and the air immediately above the soil. Wind can reduce the concentration of NH_3 in the air right above the soil surface, increasing the concentration gradient and thereby increasing NH_3 volatilization.

As shown in Figure 2.4, soil pH plays an important role in NH_3 volatilization, because it controls the proportion of ammoniacal N present as NH_3 . The decomposition of animal manures and the hydrolysis of urea fertilizers consume H^+ ions from the soil, which leads to a pH increase. The magnitude of this pH increase depends on buffer capacity of the soil. Consequently, soils with a large buffer capacity commonly show smaller NH_3 losses than soils with a small buffer capacity (Figure 2.4).



Source: (Ferguson, et al., 1984)

Figure 2.4: Effect of soil hydrogen buffering capacity on soil pH and NH_3 loss after urea application

Volatilization of NH_3 is also affected by soil water content, with rates of NH_3 loss increasing as soil water content increases. Losses are increased in wetter soils for at least two reasons: 1) release of NH_4^+ from organic sources such as urea is enhanced under wetter conditions, and 2) a greater proportion of the NH_4^+ is not adsorbed by the soil exchange sites and remains in the soil solution at higher soil water contents (Thompson and Meisinger, 2005).

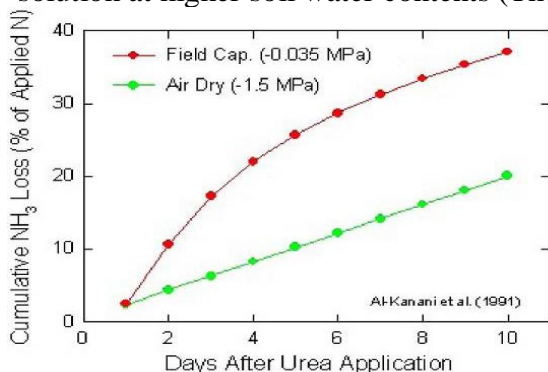


Figure 2.5: Effect of soil water content on NH_3 loss from surface-applied urea solutions.

In summary, some of the conditions that enhance NH_3 volatilization from surface-applied manures and N fertilizers are pH above 7, small buffer capacity, small cation exchange capacity, elevated temperature, high wind speed, and high moisture of the soil.

2.8 Methods to measure NH_3 volatilization

The methods available to measure NH_3 losses under field conditions can be classified into micrometeorological methods, enclosure methods, and isotopic methods. In general, micrometeorological methods are preferred over other methods because they involve minimum disturbance of the environment and thus are likely to yield more realistic results. Chapter 4 of this study explains the method used to measure the ammonia loss with incorporation of the wind speed meter. The source of ammonia used for this study is the urine effluent from the struvite reactor. The method used is based on comparing the unknown ammonia volatilization from drip effluent and bucket application of urine. A standard comparison method, developed by (Vandere, R, 1998) with modification was used for measuring ammonia NH_3 volatilize. The method is based on trap diffusion sampling 15cm from the ground. On each plot, measurements were carried out to determine the concentration in the traps. Measurements were also conducted in unfertilised plot as well as reference plot.

3 METHODOLOGY

3.1 Soil Sampling

3.1.1 Sampling technique

The soil samples were collected using a T-type steel hand probe from two fields as shown in Figure 3.1. One of the two fields had been fertilized, while the second had not with urine. The sampling was done prior to the installation of drip irrigation and ammonia volatilization experiments. One kilogram of sample was required for each data point. For each area (fertilized and unfertilized) two composite samples were made by combining five individual samples that were taken at a depth between 0 to 15 cm. The same procedure was repeated for samples taken at a depth of 15 to 30 cm from the soil surface. The soil samples were air-dried and ground to pass through a Mic 500 standard test sieve and homogenized prior to use. Furthermore, four samples packed in plastic bags were analyzed to determine the moisture contents and the Total N concentration. The soil pH was measured from the soil solution made of 20g of sieved soil. Organic matter in the soil was determined by the Walkley-Black method (NARC laboratory).

The lower depth was analyzed for nitrate ‘as nitrogen’ (nitrate-N), and sulfate-sulfur (sulfate-S) because both nutrients are very soluble and can move in the soil more readily than other nutrients. Therefore, high levels of nitrate-N can accumulate at deeper depths. The parameters selected for analysis at the Nepal Agricultural Research Council (NARC) soil laboratory were pH, moisture content, nitrogen, phosphorus, potassium, organic matter, sodium, magnesium and soil texture.



Figure 3.1 Soil sampling using the hand probe from fertilized (L) and unfertilized areas (R)

3.2 Ammonia volatilization

Four field plots were used for the ammonia volatilization experiments. On the first plot urine was spread with a bucket (traditional fertilization method). On the second plot effluent was applied through drip irrigation. The third plot was not fertilized at all. It was used to determine the background ammonia concentration in the air. The fourth plot was the reference plot. It was exposed to the same environmental conditions as the other plots, but the urine was held in a basin (1.2 x 1.8 m²). Here, ammonia could only be lost by volatilization. The first three plots were in the flat area 7.5m apart and about 25m from the reference plot, to avoid background ammonia from the reference plot. The urine volumes used per experiment were 20, 41 and 45 Lts.

Traps were installed to capture ammonia volatilized on all four plots. Each plastic trap (11x11x11 cm) was filled with 100 ml of a 2% boric acid solution. The traps were installed 15 cm above ground. The four sides of the trap were open to allow air to pass through so that ammonia, as it passed over the acid, would be absorbed. Each hour, 10ml samples were collected from the 4 traps one on each plot. At the same time a 60 ml sample was taken from the basin on the reference field.

The basin was also sampled at the beginning of the experiment. Additionally, the volume of the basin was measured at each sampling with the help of a gauge (Figure 3.2). The duration of the experiment was usually 8 hours.

All samples were analyzed for ammonia. A well mixed sample was first filtered through a membrane 0.7 µm filter and then through a 0.45 µm membrane filter with specification Schleicher & Schuell ME 25121 STL090. For the boric samples 1ml of Sodium Hydroxide NaOH was used for each sample to neutralize the solution directly before the measurement. The samples were measured with a Hach DR 2000 spectrophotometer in Figure 3.7 using the salicylate method. The dilution for the basin samples was done in two step 1:100 and 1:10'000; for the trap samples the dilution steps were 1:10 and 1:100 (using Pipet Socorex no. 06072637 and 12081204). The protocols for the analysis of ammonia are described in Standard Method for the Examination of Water and Wastewater (APHA, 1998) (APPENDIX B: Ammonia Salicylate Method).

The basin samples were also analyzed for pH(using pH meter WTW 315i), temperature (using thermometer) and electric conductivity (EC) (WTW LF 340) Figure 3.8. Both pH and EC meters were calibrated according to the manufacturer's instructions for the measurement of sample temperature and standard buffer solutions. Other parameters measured were wind speed using an anemometer and air temperature at the basin. An anemometer was positioned at the height of 1.2m above the ground. The air speed was measured every hour at the same time with the NH₃ sampling from each plot.



Figure 3.2: Ammonia trap

3.2.1 Volume measurement

The ammonia measurements from the reference plot were used to calculate an ammonia transfer coefficient. The use of a transfer coefficient is based on the assumption that traps on all plots capture the same fraction of volatilized ammonia (Vandre. R, 1998). The transfer coefficient can be calculated from the trap and basin measurements on the reference plot. By dividing the amount of ammonia accumulated in the traps by the transfer coefficient, one can calculate the amount of ammonia volatilized from a fertilized field.

The formula for the transfer coefficient is defined as follows:

$$K_{transfer} = \Delta NH_{Trap,ref} / \Delta NH_{Basin,ref} \quad (1)$$

$$\Delta NH_{applied,fert} = \Delta NH_{Trap,fert} / K_{transfer} \quad (2)$$

$K_{transfer}$	transfer coefficient
$\Delta NH_{Trap,ref}$	the total ammonia ($NH_3 + NH_4^+$) accumulated in the trap (reference field) [mgN]
$\Delta NH_{Basin,ref}$	the total ammonia ($NH_3 + NH_4^+$) lost from the basin (reference field) [mgN]
$\Delta NH_{Trap,fert}$	the total ammonia ($NH_3 + NH_4^+$) accumulated in the trap (fertilized plot) [mgN]
$\Delta NH_{applied,fert}$	the total ammonia ($NH_3 + NH_4^+$) lost from urine applied to the soil [mgN]
'fert'	The notation 'fert' can stand for bucket fertilization or drip fertigation.

The total ammonia accumulated or lost, respectively, is calculated cumulatively. Thereby, two corrections have to be considered. First, one has to add the total ammonia, which has been withdrawn by sampling to $\Delta NH_{Basin,ref}$, $\Delta NH_{Trap,ref}$ and $\Delta NH_{Trap,fert}$. Second, the background ammonia, which was measured in the trap of the water irrigated field, has to be subtracted from $\Delta NH_{Trap,ref}$ and $\Delta NH_{Trap,fert}$.

The $\Delta NH_{Surf,fert}$ values can be used to calculate the volatilization rate $r_{NH,fert}$ and the fraction of total ammonia lost f_{fert} .

$$r_{NH,fert,i} = (\Delta NH_{Basin,fert,i} - \Delta NH_{Basin,fert,i-1}) / (t_i - t_{i-1}) \quad (3)$$

$$f_{fert} = \Delta NH_{applied,fert,i} / NH_{fert,0}$$

$r_{NH,fert}$	volatilization rate at time i [gN/h]
f_{fert}	fraction of total ammonia lost [-]
$\Delta NH_{applied,fert,i}$	total ammonia lost from urine applied to the soil up to time t_i
$NH_{fert,0}$	initial amount of total ammonia in urine applied to the soil

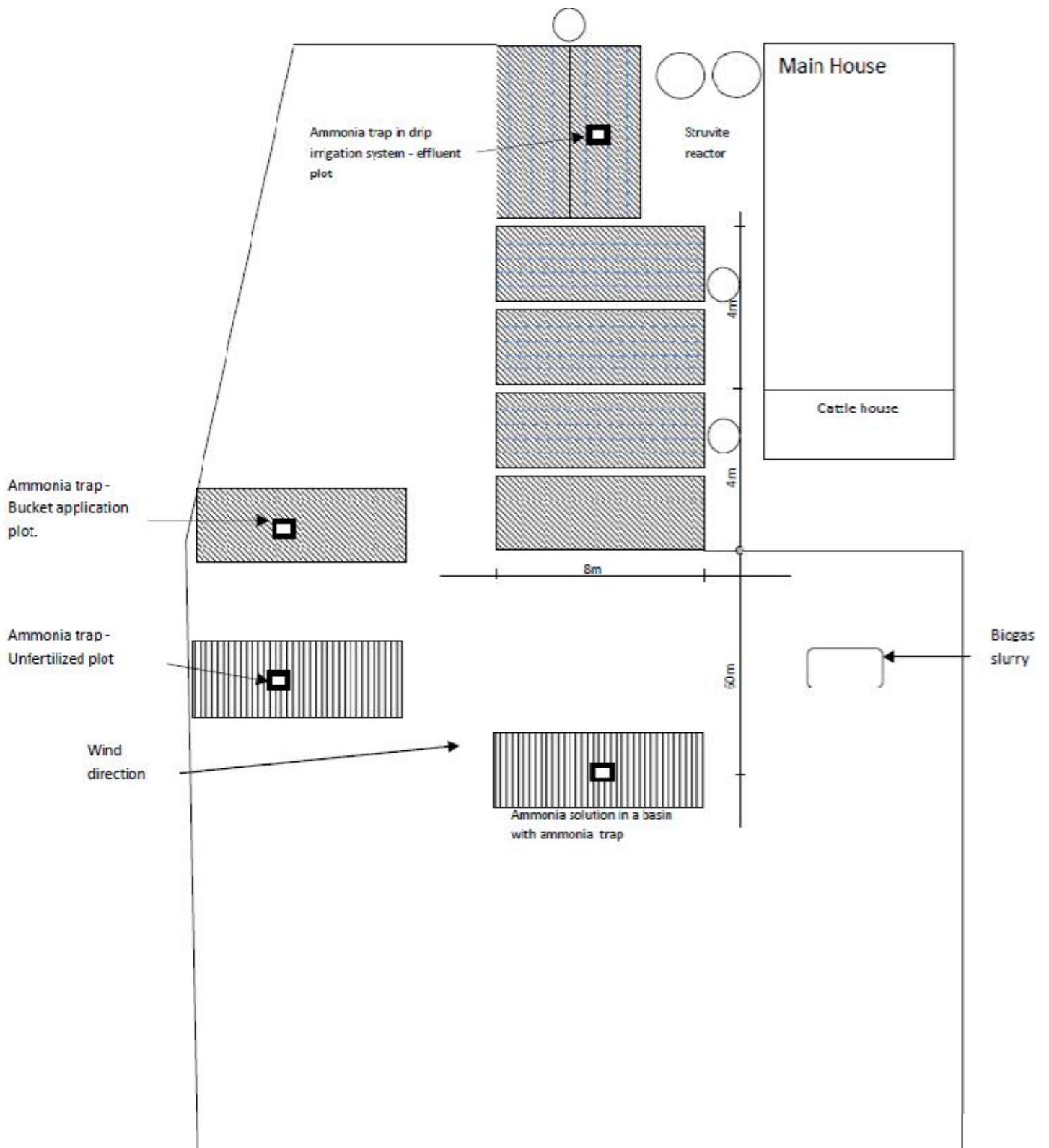


Figure 3.3 Ammonia -NH₃ experimental setup



Figure 3.4: Ammonia basin at reference point with trap and anemometer on sideline.



Figure 3.5: Gauge for urine volume



Figure 3.6: Wind speed measurements- Siddhipur



Figure 3.8: pH and Electro conductivity meter



Figure 3.7: Spectrophotometer DR 2000

3.3 Drip irrigation

3.3.1 Experimental set up

The experiments for drip irrigation were conducted with the following liquid in the plots; effluent, urine (influent to the struvite reactor), their dilutions and water. Five plots have been established for that purpose as shown in Figure 3.11. Each plot had an area of $2 \times 8 \text{ m}^2$ and it was equipped with a tank (50 L, 1.2m above ground, operating head of 37cm) and 2 drip lines (12 m long, 10mm diameter, 20 emitters at an interval of 60 cm, diameter of the emitters 0.7 mm, weight of drip line 350 g (Figure 3.10).



Figure 3.9: Drip lines layout in Siddhipur



Figure 3.10: Drip line

In order to carry out the experiments at the same conditions, each tank was operating from the same head (37 cm) for better comparison on clogging. The first step was to measure the head in tanks and then release the tape to allow effluent into the drip lines. The head in all tanks was measured every 5 minutes so that the experimental errors committed are minimized. Onions were planted in each plot, 2 drip lines of a total of 40m were installed for each plot.

Liquid applied per irrigation and irrigation frequency

Low-application, high-frequency irrigation has been identified as the ideal irrigation strategy for maximizing plant growth. Averages of 42lts per plot were applied in one day. The typical range for drip irrigation frequency was at 2-3 days.

One reason for the need for more frequent irrigation with drip systems is simply that less liquid is applied per irrigation cycle. Water quality measurements in Table 3.1 were conducted to avoid emitter plugging problems resulting from reactions of the fertilizer with the irrigation water. The fertilizer source must be soluble. Chemical reactions between fertilizer materials can result in the formation of precipitates which can plug the irrigation system. However, no threat of full clogging due to the low Ca and Mg.

Table 3.1: Water chemical constituents

NH4-N	[mg/l]	0.13
PO4	[mg/l]	<0.2
Cl	[mg/l]	0.6
SO4	[mg/l]	7.7
TIC	[mg/l]	34
COD	[mg/l]	10.2
Mg	[mg/l]	5.8
Ca	[mg/l]	52
K	[mg/l]	5
Na	[mg/l]	10

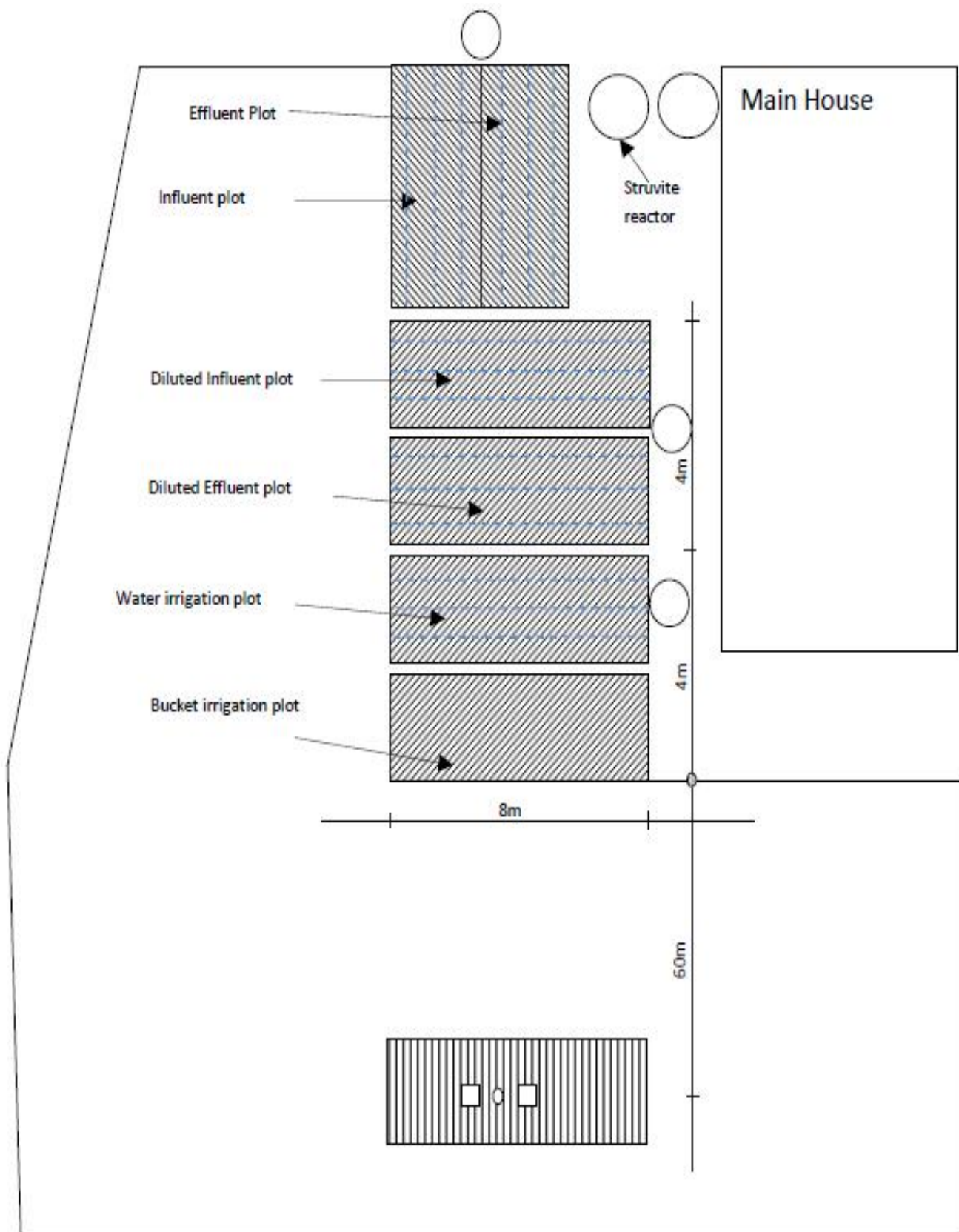


Figure 3.11: Drip irrigation layout

3.3.2 Head loss measurements

During the experiments, the head loss was measured using a calibrated piezometer attached to the tank. Measurements were taken every 5 minutes. Prior to the experiment, the composition of the effluent and influent was analysed. The parameters of concerns for effluent and influent were pH, EC, phosphorus and temperature.

In the first experiments, there was a filter in the tank, but it was too easily clogged and therefore the clogging effect on the drip lines could not be determined. Therefore, it was removed from all tanks. More trials were done after the filter was removed, and only the data collected from these trials will be presented here. The series of measurements collected from field are also attached in (APPENDIX E: Drip irrigation head measurements) the data discussed are those without filter.

4 RESULTS AND DISCUSSION

4.1 Soil sampling

The background concentration of nutrients in the soil was determined before the implementation of the research. Additionally, the soil type was determined as it has been found to have effect on ammonia volatilization. The soil sampling also had an importance for laying-out the drip lines to avoid encountering preliminary clogging from the surroundings and also in deciding whether to use subsurface or surface drip lines.

The soils examined were slightly acidic with a pH range of 5.3 to 6.3, and hence it is appropriate for an alkaline fertilizer such as struvite effluent. Furthermore, Ammonia losses have a tendency to increase with higher soil pH because of the increased dissociation of NH_4 to NH_3 , thus increasing the potential for volatilization.

The soil type in Siddhipur was found to be silt clay loamy. The soil had the capability to retain moisture.. Moisture content in soil has an effect on volatilization since more water will cause less volatilization. This type of soil can cause clogging from silt when the drip lines are sub-surfaced, this made the drip lines to be laid on the surface.

Total nitrogen was found to be medium at the range of 0.1-0.3% TN (Minbhanan, 2000). Therefore, the soil could benefit from more nitrogen. In general, Nepalese soils are low in nitrogen content (MAC, 2003).The effects of supplying additional nitrogen to plants through fertilizers are quite visible in terms of plant growth and greenness. Therefore, farmers give priority to nitrogen over other nutrients.

The phosphorus was also found to be at the medium level which almost means that the soils could benefit from the application of struvite and its effluent.

Calcium (Ca), sodium (Na) and magnesium (Mg), all contribute to the Soil Adsorption Ratio (SAR). To avoid deterioration of soil due to salts accumulation, the SAR result obtained will be the baselines for this study and the ongoing ones at Siddhipur. The laboratory results are summarized in Table 4.1. The range for SAR is 0 to 3 which is satisfactory for effluent application (Table 0.2).

Table 4.1: Baseline soil test information of experimental site (composite soil samples)

Soil parameters	Soil pH	Organic matter %	Available K_2O Kg/ha	Available P_2O_5 Kg/ha	Moisture content %	Total Nitrogen %	Ca me/l	Na me/l	Mg me/l	S me/l	Soil Texture	SAR
Fertilized soil												
depth 0 to 15cm	6.3	4.913	100.8	743	10.65	0.181	18.0	6.52	5.2	15	CL	1.9
Soil 15 to 30	5.9	2.063	67.2	230	14.15	0.137	17.8	10.8	6.2	10	CL	3.1
Unfertilized soil												
Soil 0 to 15	5.3	4.654	80.6	359	14.51	0.173	22.2	8.69	1.4	10.25	S	2.5
Soil 15 to 30	5.4	5.689	73.9	266	34.45	0.203	18.7	9.56	4.9	10.1	SCL	2.7

CL – Clay loam,

S- Silt

SCL – Silty Clay Loam

4.2 Ammonia volatilization

The method developed for measuring ammonia volatilization was found to be adequate in terms of measuring the amount of ammonia volatilized.

In order to get more significant results, the amount of urine that was used in the reference basin was the same as to the applied urine in plots. In this way it was easier to compare the volatilization from bucket and drip effluent as they both use the same amount of urine and are subjected on the same conditions as the reference plot.

Ammonia volatilized from the bucket irrigation was greater than the amount of ammonia that volatilized from the effluent in the drip line Figure 4.6.

Table 4.2: Bucket and drip effluent ammonia volatilization rate

Bucket irrigation with struvite reactor effluent

Time	Volume Trap	Sample Volume Trap	Total Ammonia in Trap Conc.	Ammonia in Trap Amount	Cumul. Change Trap	Estimated Total Ammonia Loss	Volatil. Rate	Wind speed
[h]	[L]	[L]	[mgN/L]	[mgN]	[mgN]	[mgN]	[mgN/h]	[m/s]
0.0	0.10	0	0	0	-	-	-	0
1.0	0.10	0.01	0.6	0.06	0.060	5275	5275	0
2.0	0.09	0.01	1.3	0.117	0.123	7714	2439	0
3.0	0.08	0.01	1.7	0.136	0.155	7807	93	1.2
4.0	0.07	0.01	2	0.14	0.176	7488	-319	1.7
5.0	0.06	0.01	2.7	0.162	0.218	8398	910	4.5
6.0	0.05	0.01	3.2	0.16	0.243	12701	4303	3.2
7.0	0.04	0.01	4.1	0.164	0.279	13105	404	0.9
8.0	0.03	0.01	4.4	0.132	0.285	13935	830	1.2

Drip-irrigation with struvite reactor effluent

Time	Volume Trap	Sample Volume Trap	Total Ammonia in Trap Conc.	Ammonia in Trap Amount	Cumul. Change Trap	Estimated Total Ammonia Loss	Volatil. Rate	Wind speed
[h]	[L]	[L]	[mgN/L]	[mgN]	[mgN]	[mgN]	[mgN/h]	[m/s]
0.0	0.10	0	0.0	0	-	-	-	0
1.0	0.10	0.01	0.0	0.000	0.000	0	0	0
2.0	0.09	0.01	0.1	0.009	0.009	564	564	0
3.0	0.08	0.01	0.3	0.024	0.025	1259	695	1.2
4.0	0.07	0.01	0.6	0.042	0.046	1957	698	1.7
5.0	0.06	0.01	0.7	0.042	0.052	2003	46	4.5
6.0	0.05	0.01	1.1	0.055	0.072	3763	1760	3.2
7.0	0.04	0.01	1.2	0.048	0.076	3570	-193	0.9
8.0	0.03	0.01	1.6	0.048	0.085	4156	586	1.2

Generally, the rate of ammonia volatilization after the application of effluent through bucket irrigation was greater than the rate of volatilization from the drip irrigation. The results of rate of ammonia volatilization in the plots with application of effluent through drip irrigation and bucket, the background and the reference field are shown in Table 4.2 and ammonia losses for the experiments are in APPENDIX D: Ammonia loss computations.

The rate of volatilization from effluent application from drip irrigation was higher on 18 February peaking at a rate of 1760 mgN/h at a temperature of 25°C and then it dropped to 453 mgN/h.

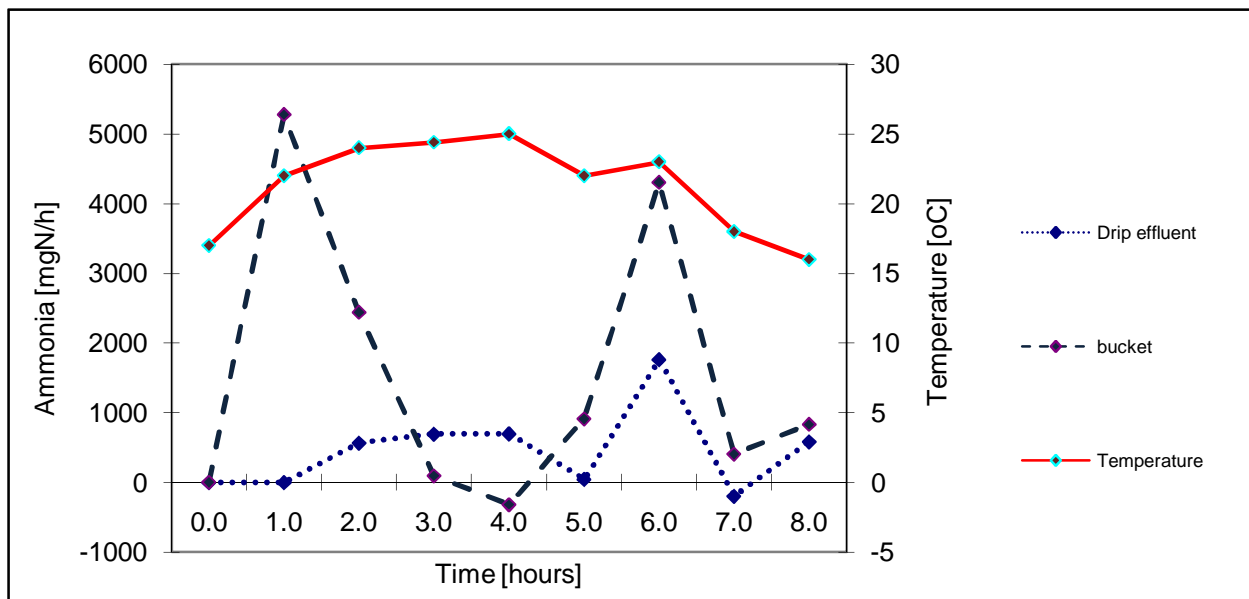


Figure 4.1: Ammonia volatilization in bucket and drip effluent- Temperature effect (18 February 2009)

The study with drip effluent irrigation showed less ammonia volatilization when comparing to bucket application. While bucket volatilization was peaking at 1 hour the drip effluent was 0 mgN/h and to temperature effect it raise up to 697mgN/h in 4hrs it then decreased by 67%. Wind effect raises it to reach 586mgN/h.

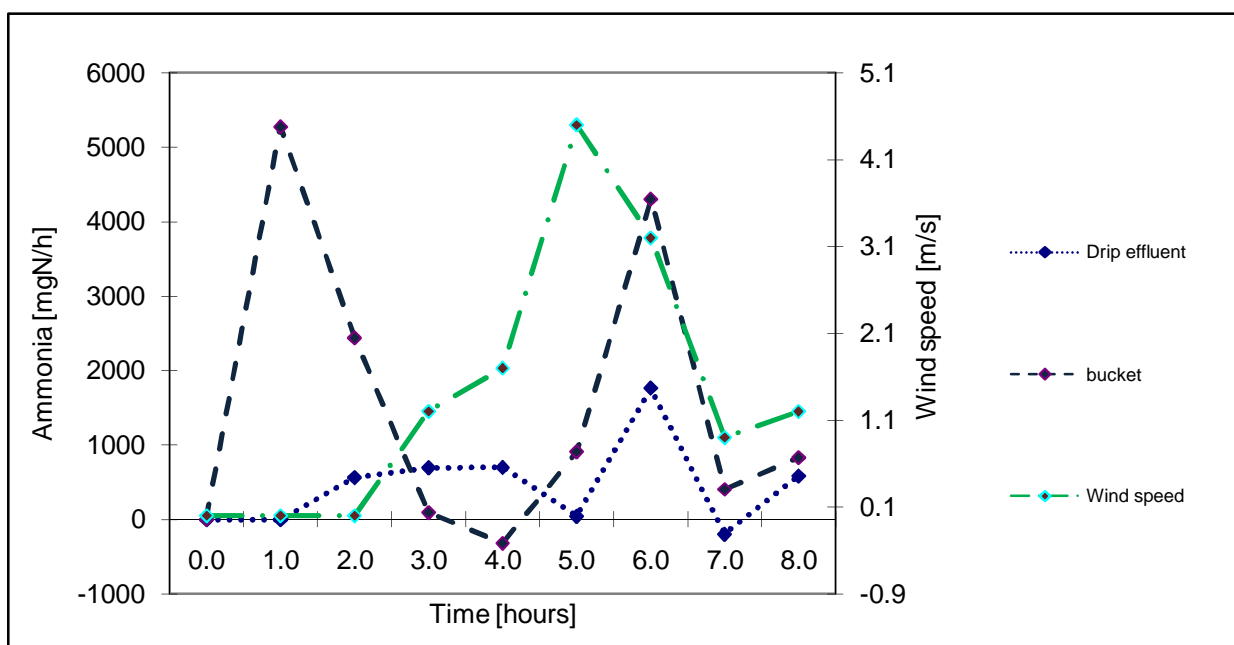


Figure 4.3: Wind effect on volatilization bucket and drip effluent. (18 February 2009)

Volatilization of ammonia from bucket application is very rapid, with most of the loss within the first 2 hours. Ammonia fluctuation rates are highest immediately after application and often decrease to 0 in one hour before the wind effect raise it again to 4303mgN/h 6 hours from application.,11% (17,635.20mgN) of the total ammonia-N applied to using bucket was volatilized within 8 hours, with 30% of this loss coming on the first hour.

Consistently greater rates of ammonia volatilization from the bucket application caused appreciable differences in cumulative loss Figure 4.4. Most of the difference in total loss between the two, effluents dripped and bucket application occurred within 8 h of after application.

The pattern of loss observed in this study was generally correlated with reference field data for ammonia loss (see APPENDIX F: Ammonia Volatilization bucket and drip effluent application)

The results from this study showed that the potential for re-using effluent could be beneficial if applied through the drip effluent to the plots, this will reduce ammonia volatilization loss from surface applications.

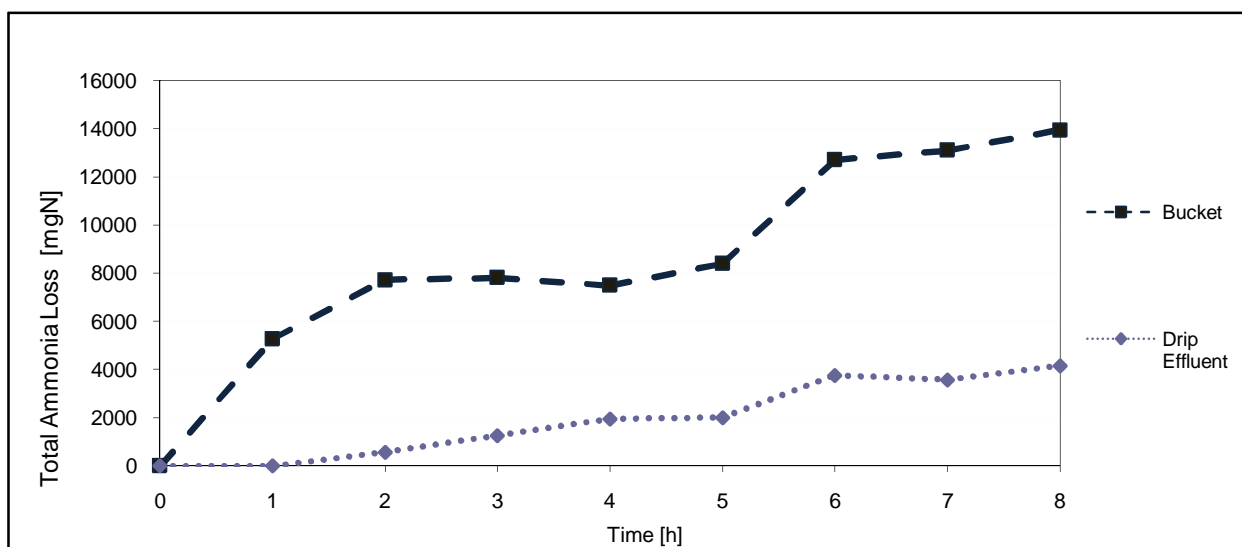


Figure 4.4: Total ammonia loss from bucket and drip effluent (18 February, 2009)

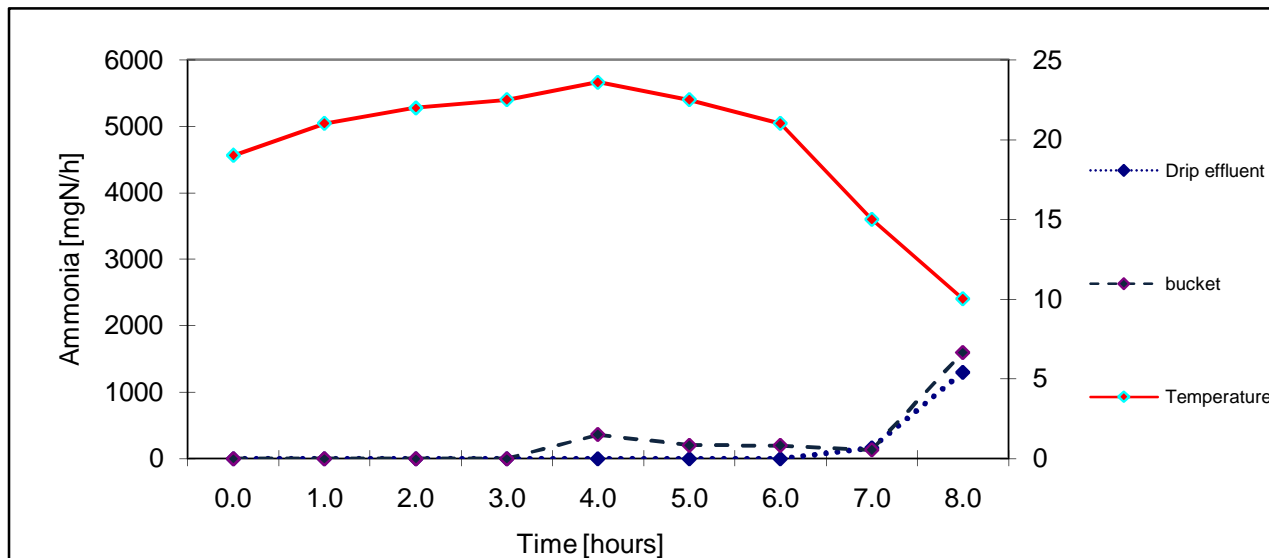


Figure 4.5 : Ammonia volatilization bucket application and drip effluent (13 February, 2009)

In this experiment in Figure Figure 4.5 the rate of ammonia volatilization was 0 mgN/h up to 3hrs for both buckets and effluent on drip application. However, later on the 4th hour bucket application was dominant on volatilization showing 360mgN/h and 1598mgN/h at the end experiment. These are 23% more volatilization than in drip effluent application.

These data suggest that climatic conditions need to be considered when predicting total ammonia volatilization loss in relation to effluent application. This may be particularly relevant in Nepal and other places where there are large seasonal changes in temperature. The average temperature was 18°C while the peak for Nepal is 30°C from April to May. The graph in Figure 4.5 shows that indeed temperature is of the main factor for ammonia volatilization. Though at the initial hours of experiments the volatilization was low, the reason was that the trap was positioned in the tilled land.

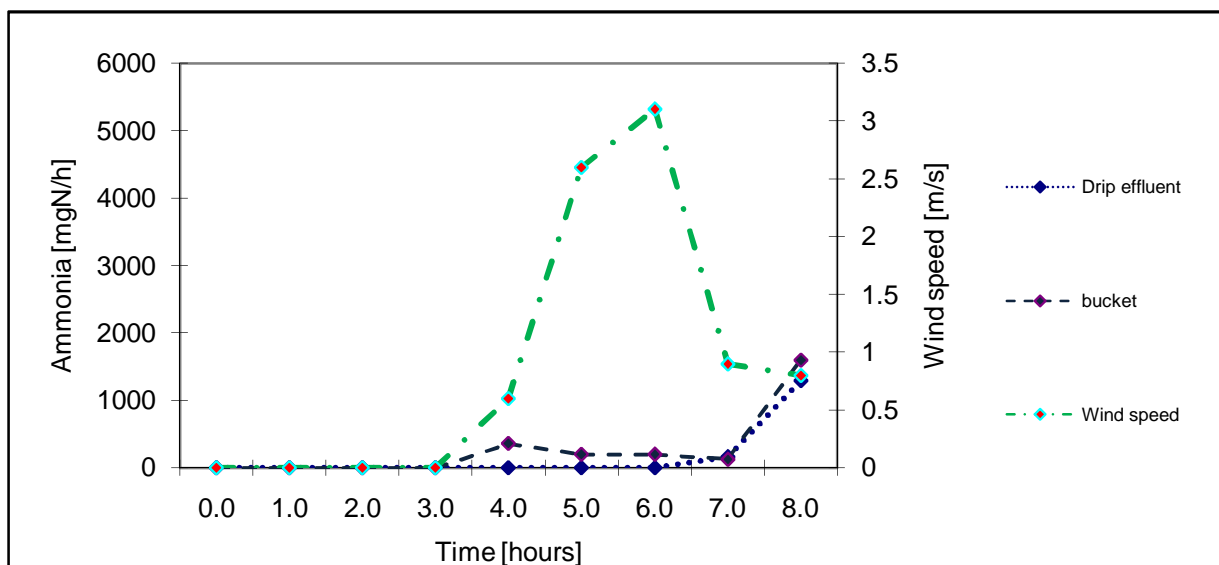


Figure 4.6: Ammonia volatilization -bucket and drip effluent application; Wind effect (13 February, 2009)

The study with drip effluent application in Figure 4.6 showed no ammonia volatilization at the up it reaches 6 hours. This are the periods in which ammonia volatilization would normally be expected. The wind delayed effect which started at 3hrs raises the volatilization rate in hour 7 and 8. Volatilization increased from 0 to 1294mgN/h at the end of 8hrs.

The low volatilization in drip irrigation could be due to the grown onions that reached the level of the trap. According to Haper and Sharpe (1995) plants can have a significant impact on ammonia transport because they can both absorb and desorb ammonia. Under conditions of low soil N or high atmospheric NH₃ concentrations, plants absorb NH₃. Under conditions of high soil N or low atmospheric NH₃ concentrations, plants volatilize NH₃.

Table 4.3: Percentage of N volatilized as ammonia after application of effluent.

Method of application	January, 09	February 13	February, 18
Bucket application	7.03	3.08	10.89
Effluent drip irrigation	5.02	2.57	4.52

Ammonia losses were 3.6 and 1.9 times greater from bucket effluent application more than from drip applied effluent applied. An average factor of 2.3 is suggested when relating ammonia loss from dripped effluent and bucket application.

A sharp increase in ammonia volatilization in response to effluent application, especially in the first four hours after application, was observed during experiments (see Figure 4.1). Bucket peak volatilization rate was at 5641mgN/hr on trial 1 and 3763mgN/hr of effluent by dripping. The ammonia volatilization at the end of 8 hours after application was 11% as shown in Table 4.3.

Total loss due to ammonia volatilization during 8 hours after effluent application ranged from 556 mgN and 2,099 mgN. Expressed as a percentage of total N applied, the impact of ammonia volatilization becomes clearer, with losses ranging from 3% to 11%. These losses are lower than those reported in other studies which reported a 53% loss (Bakhsh, et al., 2005). However, the majority of ammonia volatilization studies are not based on human urine.

The relatively losses of N due to ammonia volatilization observed in this study may be explained as follows; A possible explanation for the ammonia volatilization losses observed in this study centres on moisture. In general, and according to literatures (Hassanli, et al., 2008), low relative humidity enhance ammonia volatilization.

Again the measurement taken from the fields irrigated with a bucket showed low volatilization

\Table 4.5 because the land was freshly tilled. The tilled soil quickly absorbed the ammonia and hence less volatilization can be recorded.

Table 4.4: Summary conditions – Ammonia Reference plot

Date	Volume of urine applied [L]	Average ammonia concentration [mgN/L]	Average pH	Average temperature [°C]	Temperature range [°C]	Average wind speed [m/s]	Soil conditions
January 14 th	20	1989	8.61	12.72	(4.0 -23.0)	0.43	
February 13 th	41	2444	8.45	19.62	(10.0 -23.6)	0.89	Tilled
February 18 th	45	2922	8.63	21.27	(16.0 - 25.0)	1.41	

\Table 4.5: Summary volatilization rate- bucket and drip effluent

Date	Plot	Average ammonia volatilization rate[mgN/h]	Maximum ammonia volatilization rate[mgN/h]	% of Ammonia loss	Comparison of ammonia loss Bucket and drip effluent [mgN]
January 14 th	Bucket application	95	4934	7.0	3935
	Drip effluent application	152	1143	5.0	2811
February 13 th	Bucket application	310	1598	3.1	4668
	Drip effluent application	182	1294	2.5	3209
February 18 th	Bucket application	1742	5275	11.0	17635
	Drip effluent application	520	1760	4.5	6412

Volatilization differences between bucket and drip effluent application.

To enable comparison between the two applications, N losses as NH₃ have additionally been reported as percentage of the total N applied in

\Table 4.5. the table shows the volatilization Losses of NH₃ were very low, close to 2% of the applied N, when the urine was applied directly into the soil by drip effluent application. The corresponding values of bucket application were higher than the drip for each experiment conducted. The total NH₃ losses did not exceed 11% for all the experiments.

The NH₃ absorption by active vegetation that was suggested in Harper's (1995) research also appears to apply to the data collected for this study. Figure 4.1 indicate a sharp decrease of NH₃ to the background levels. Wind and temperatures were variable for different times of the day; it is possible to speculate that the vegetation was acting as a net absorber of NH₃ when the ammonia shows a steep gradient. Harper's work concluded absorption of NH₃ by the plant from the air was related to the amount of atmospheric NH₃ surrounding the plants. Harper noted several factors that sometimes correlated with absorption but stated the concentration of NH₃ in the air was the most consistent factor affecting NH₃ absorption and found it would supersede the other factors.

4.3 Drip Irrigation

This section describes the results of studies concerning drip irrigation following the application of effluent. Each drip irrigation system was used multiple times, and it is the trials after the removal of the filters presented herewith. In this case the evidence of clogging was found to be cumulative in all the plots experimented. The trials are reported as follows

Influent Application

Between Trials 1 and 2 the flow rate for influent in the drip line decreased by 11 L/hr. The decrease is equivalent to 39 %. The reduction of flow in the drip system is an indication of clogging. The reduction of flow has been found to increase the time for irrigation, 1.6 times in the influent tank. Figure 4.11 shows the difference of flow rate from Trial 1.

Even when the flow was reduced by 39%, the drip lines were not fully clogged. The drip lines, when checked, showed no visible precipitation at the end of the line. This is likely because of the thin layer of scum on top of the urine which, when it goes through the drip line, attaches itself to the wall of the pipe. The low pressure of the drip line facilitates the build-up of the tiny layer that blocks the emitters and decreases the flow. The foaming observed in Figure 4.7 accelerates the blockage of emitter. The reoccurrence of foaming in the drip line system finally tends to decrease the flow rate and hence increase the incidence of clogging.. This shows that in the case of using influent, pre-treatment may have to be considered.



Figure 4.7: Foaming at the emitter in the drip line



Figure 4.8: Partial logged filter

Figure 4.9: Snails at the bottom of the effluent tank

Diluted Influent application

Dilution of influent is the normal and regular practice to most of the Siddhipur farmers (Tuladhar, 2008). Urine has been either used by adding it to compost or diluting it and applying to the fields. The results of using diluted influent in drip irrigation showed a flow rate reduction of 48%. Figure 4.10 shows part the results of Trials 1 and 2.

Effluent

The struvite reactor efficiency was 90- 95% to retain the struvite. Therefore, there should be less clogging because much of the precipitation has been removed through the reactor. Even without the filter fitted the trend shows no sign of full clogging.

The effluent showed a small variation in the time of application (flow rate). The early application of effluent showed foaming at the emitters Figure 4.7 which disappeared on multiple applications and later ending up reducing the emitter flows and hence prolonged the time for application.

No total clogging was detected. However, the time still considered long that will end on causing particles and organism to reproduce in the drip line. The flow rate average in the system was 36L/h (Figure 4.12). A few snails were visible in the effluent tank Figure 4.9 and therefore to prevent them going to the drip line the tap was closed once the effluent was finished. .

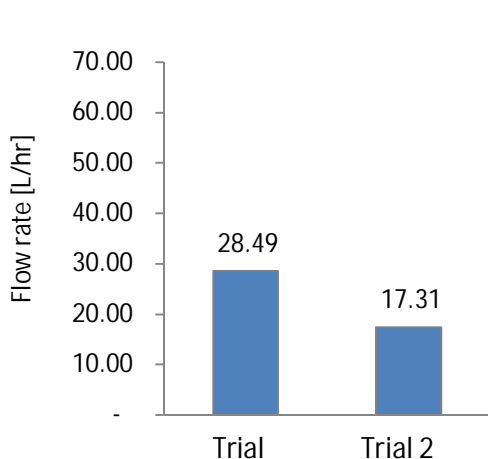


Figure 4.11: Influent flow rate

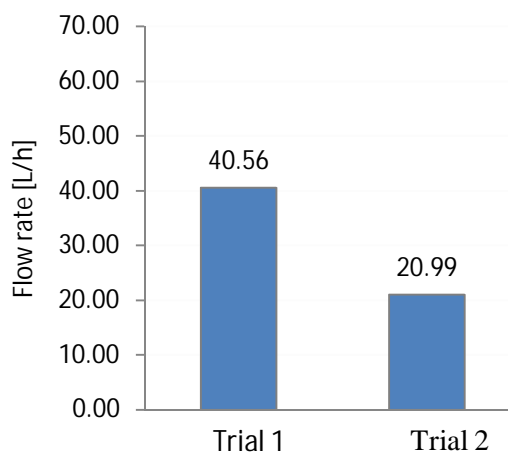


Figure 4.10: Diluted Influent flow rate

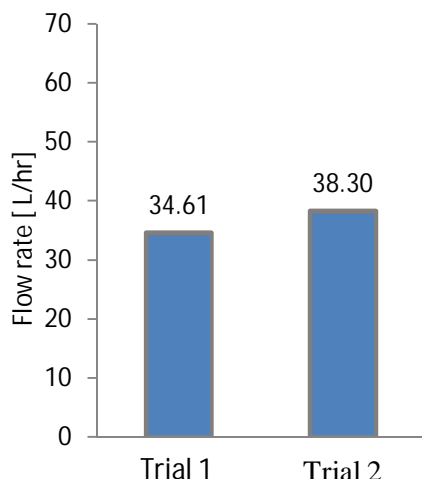


Figure 4.12: Effluent flow rate

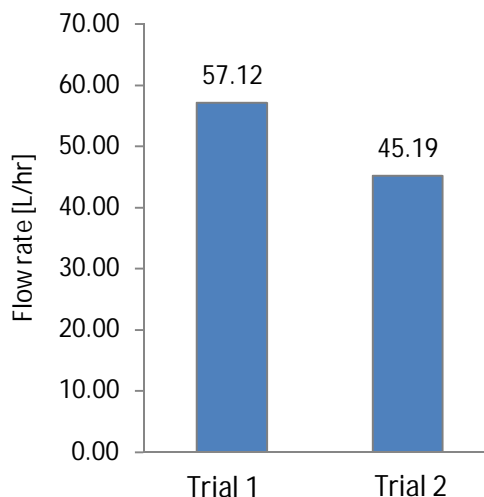


Figure 4.13: Diluted effluent flow rate

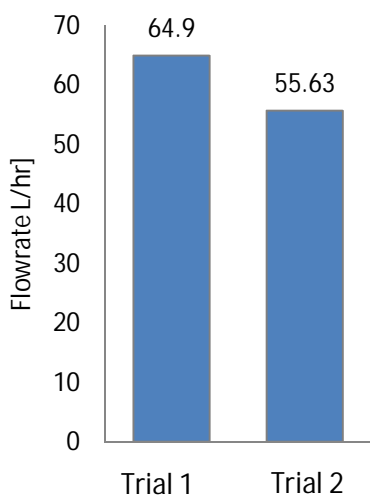


Figure 4.14: Water flow rate

Diluted effluent

The effluent was diluted with water by half and as a result, the application showed the reduction of flow. In Figure 4.13 Diluted effluent showed a gradual decreasing of flow rate at 21%. This is the sign of clogging. This is because the effluent used has less from precipitation. This shows that the dilutions of 1:2 are more suitable for the drip irrigation and are rated second in Figure 4.15.

Water

The study uses well water for irrigation to compare the flow rate that would be normal for the drip system. The flow rate was at the range of 56. and 65 L/hr. Therefore, 62L/hr is an average flow rate on comparing to others this system has little sign of clogging. The drip kit operated in the same conditions like in the other kits, from Figure 4.14, the decreasing time of application has a positive effect on emitter discharge, the lesser the time the higher the flow rate (APPENDIX E: Drip irrigation head measurements). The figure below is assuming the water flow rate at 55.63l/h to be 100% non clog.

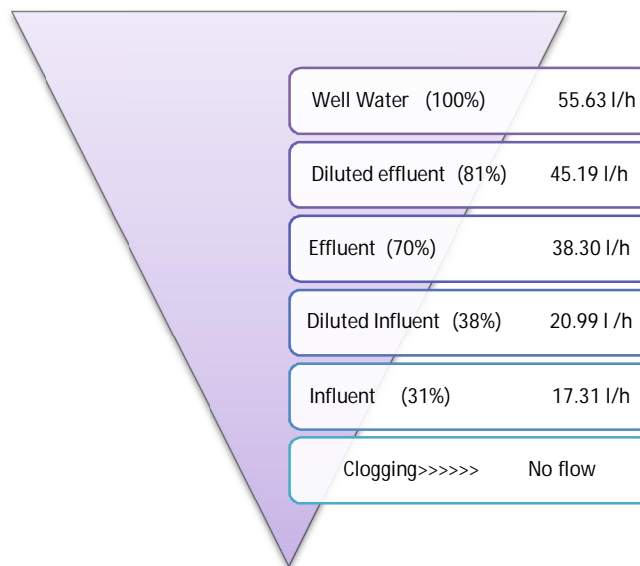


Figure 4.15: Clogging rate; decrease of flow rate in plots.

5 CONCLUSIONS

5.1 Ammonia volatilization

The hypothesis that drip fertigation causes less ammonia volatilisation than bucket fertilization was proven to be correct. In addition, the measurements added to the understanding of factors that influence the ammonia volatilization:

1. Ammonia losses were 3.6 and 1.9 times greater from bucket application than from drip applied effluent with drip irrigation. An average factor of 2.3 is suggested when relating ammonia loss from dripped effluent and bucket application.
2. Wind speed and temperature have shown to have influence on total ammonia loss in both bucket application and drip irrigation by effluent..
3. A sharp increase in ammonia volatilization in response to effluent application, especially in the first four hours after application, was observed during experiments (see Figure 4.4). The peak volatilization rate from bucket application was at 5641mgN/hr and 3763mgN/hr of effluent by dripping. The ammonia volatilization loss at the end of 8 hours after bucket application was 11%.
4. Total loss due to ammonia volatilization during 8 hours after bucket effluent application ranged from 556 mgN and 2,099.43 mgN. Expressed as a percentage of total N applied, the impact of ammonia volatilization becomes clearer, with losses ranging from 3% to 11%. These losses are lower than those reported in other studies which reported losses of 50% (Bakhsh, Kanwar and Karlen, 2005) However, the majority of ammonia volatilization studies are not based on human urine and cannot be directly compared.
5. The relatively losses of N due to ammonia volatilization observed in this study may be explained by several factors. One possible explanation may be the dense and actively growing plant cover on these plots at the time of effluent application and during the sampling period. This could have caused a more rapid plant uptake of ammonia and also absorption of volatilized ammonia by plant leaves or protection by leaves. A second possible explanation for the low ammonia volatilization losses observed in this study centres on moisture. In general, and according to literature (Hassanli, Javan and Saadat, 2008), low relative humidity enhance ammonia volatilization. The sampling periods for this study were characterized by cloudy weather which could have contributed to the relatively low amounts of nitrogen lost via ammonia volatilization.
6. Temperature is another factor that may help explain why the rates of ammonia volatilization in this study were rather low. Ammonia volatilization generally increases with increasing temperature. The majority of applications were done in the morning times when the temperatures are still low. This may have been a sufficiently large difference to produce this study's lower ammonia volatilization rates and reduced N losses.
7. The ammonia loss from the reference basin was 60% in a span of 8 hours; this loss could be expected at household level if the storage facilities are not covered.

The data from this study indicate that ammonia volatilization from drip irrigation was low as in comparison with the bucket the experiment was based in 8hrs. This time frame could be important in timing of future attempts to control ammonia volatilization. Nevertheless, the data have been collected in a reliable methodology backed with ammonia standard additions.

5.2 Drip irrigation

The two main conclusions that can be observed from both experiments are;

1. That preliminary effluent from struvite can be used in drip irrigation systems without full clogging, hence the hypothesis 1 was right as effluent clog less than influent.
2. That the dilution of influent has a negative effect on emitter discharge. This effect influences all types of emitters but not equally, the field experience showed the far end emitters start clogs.
3. That influent had a faster clogging rate than effluent from the struvite reactor

All drip lines had the same tendency of increasing time for irrigation when the different quality of liquid was used. Nevertheless, this effect does not influence all types of drip equally and effluent was shown to be the fertilizer that would likely clog the least.

6 RECOMMENDATIONS

Based on the findings and conclusions formulated in this thesis, the following recommendations are hereby proposed.

Volatilization of ammonia from bucket applied urine represents a direct loss to the farmer. The use of bucket for irrigation should be avoided in the case there will be no alternative then incorporation of urine to soil had to be less than 2hrs or applied to the tilled land. A close to the ground application is recommended to minimize volatilization.

The lesson learnt from the study suggests that application of urine in the tilled land will minimize the rate of ammonia volatilization.

The effluent from struvite should be applied using drip irrigation method, the method had shown to have minimal ammonia volatilization.

Dilution of 1:2 (effluent: water) work better in the drip irrigation should use this method as their priority with the Effluents , diluted influent and influent as they have shown to have gradual decrease of flow rates in the drip lines (Figure 4.15).

The application of effluent during the windy period should be avoided as most of the volatilization are accelerated by wind.

The ammonia loss from the reference basin was found to be 60% in average in a span of 8 hours. The study recommends the storage facilities to be covered properly to avoid ammonia loss.

Drip irrigation systems, which are highly efficient for water application, are ideally-suited for effluent fertigation

Appendices

APPENDIX A: Standard Addition Method

Sample preparation for standards

N-Standards

NH ₄ -standard	777.78	mgN/L
dilution	1429	
NH ₄ -concentration of stocksolution	0.54	mgN/L

Standard Nr.	amount stocksolution [ml]	added with nanopurwater [ml]	referenc value [mgN/L]
1	24	0	0.544
2	21	3	0.476
3	18	6	0.408
4	15	9	0.340
5	12	12	0.272
6	9	15	0.204
7	6	18	0.136
8	3	21	0.068

diluted from standard 7

Input sheet additions (8 standards, 8 additions)

Substance NH4+ (salicylate method)
 Date 18-02-09
 Machine HACH DR 2000
 Matrix diluted urine
 Remarks dilution samples 1:10'000

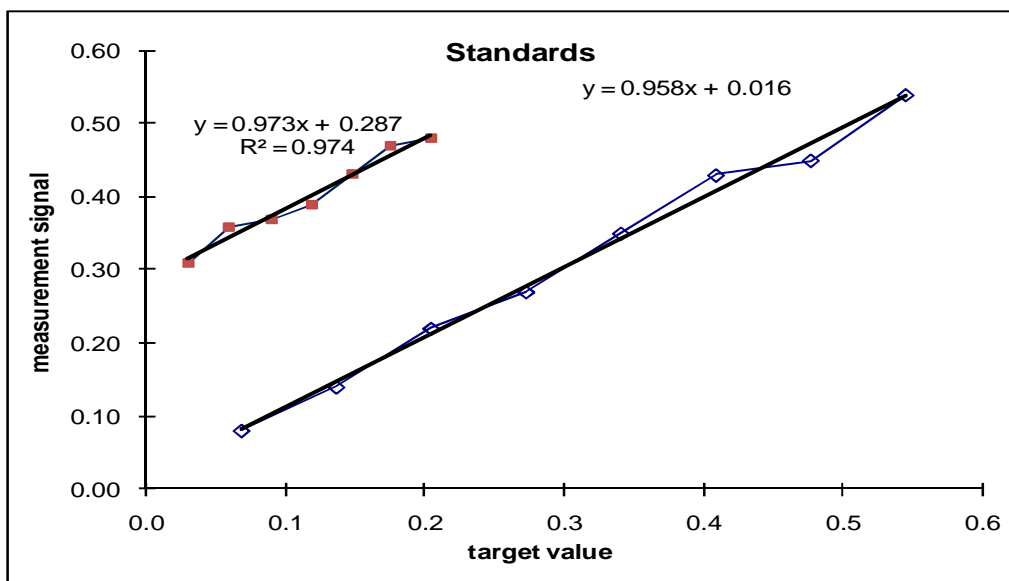
Analyst Edmund John

calibration curve:

standard #	reading [-]	target concentration x_i [mgN/L]
1	0.54	0.5444
2	0.45	0.4784
3	0.43	0.4083
4	0.35	0.3403
5	0.27	0.2722
6	0.22	0.2042
7	0.14	0.1361
8	0.08	0.0681

addition:

standard #	reading Y [-]	Δ_{target} [mgN/L]
1	0.31	
2	0.36	0.030
3	0.37	0.059
4	0.39	0.089
5	0.43	0.118
6	0.47	0.147
7	0.48	0.175
8	0.52	0.204



standard addition NH₄⁺ (salicylate method)

Date 18-02-09
 Machine HACH DR 2000
 Matrix diluted urine
 Remarks dilution samples 1:10'000

Edmund John

linear calibration curve

Standard-Nr.	reading y _i [-]	target concentration x _i [mgN/L]	measurement [mgN/L]
1	0.54	0.54	0.55
2	0.45	0.48	0.45
3	0.43	0.41	0.43
4	0.35	0.34	0.35
5	0.27	0.27	0.26
6	0.22	0.20	0.21
7	0.14	0.14	0.13
8	0.08	0.07	0.07

method standard deviation
 $s_{x_0} = 0.015$ [mgN/L]

Addition

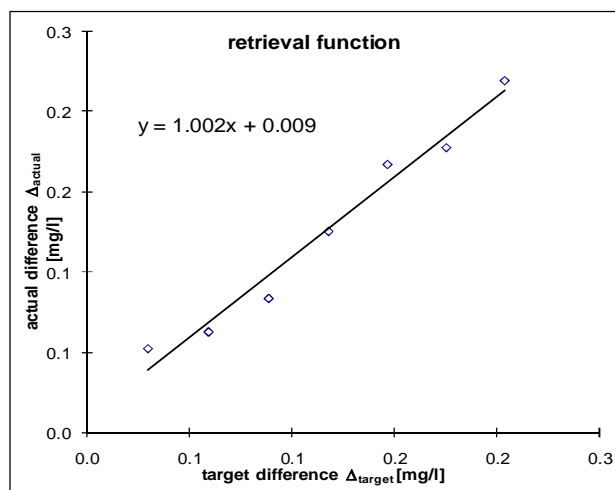
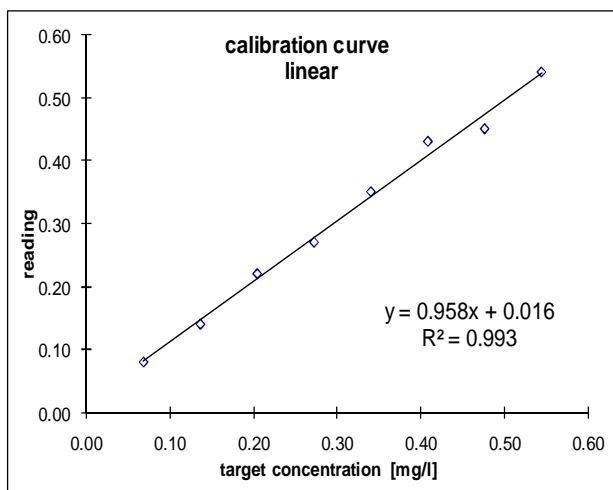
Addition-Nr.	reading Y [-]	actual value X _{actual} [mgN/L]	Δ_{target} [mgN/L]	Δ_{actual} [mgN/L]
1			0.00	0.00
2	0.36	0.36	0.03	0.05
3	0.37	0.37	0.06	0.06
4	0.39	0.39	0.09	0.08
5	0.43	0.43	0.12	0.13
6	0.47	0.47	0.15	0.17
7	0.48	0.48	0.18	0.18
8	0.52	0.53	0.20	0.22

coefficient of retrieval function
 $\Delta_{actual} = \beta * \Delta_{sol} + \alpha$

		95%-confidence interval	
		lower	upper
$\beta =$	1.00	0.81	1.19
$\alpha =$	0.01	-0.02	0.03

standard deviation of retrieval function
 $s_{y'} = 0.011$ [mgN/L]

F-Test random difference between s_{x_0} and $s_{y'}$

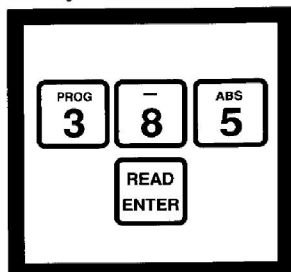


APPENDIX B: Ammonia Salicylate Method

Method 8155

NITROGEN, AMMONIA (0 to 0.50 mg/L NH₃-N) For water, wastewater and seawater

Salicylate Method*



1. Enter the stored program number for ammonia nitrogen (NH₃-N), salicylate method.

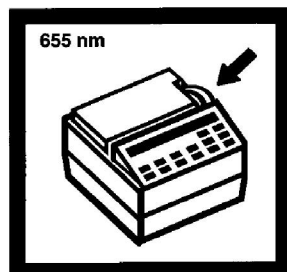
Press: **3 8 5 READ/ENTER**

The display will show:
DIAL nm TO 655

Note: DR/2000s with software versions 3.0 and greater will display "P" and the program number.

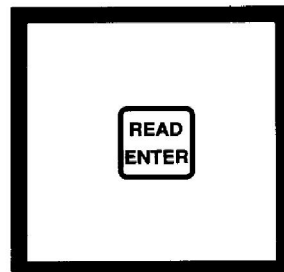
Note: Instruments with software versions 3.0 and greater will not display "DIAL nm TO" message if the wavelength is already set correctly. The display will show the message in Step 3. Proceed with Step 4.

Note: If samples cannot be analyzed immediately, see Sampling and Storage following these steps. Adjust pH of stored samples before analysis.



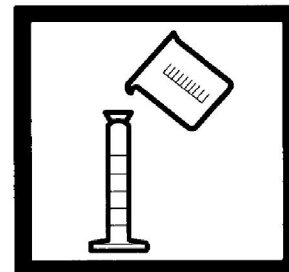
2. Rotate the wavelength dial until the small display shows:

655 nm



3. Press: **READ/ENTER**

The display will show:
mg/l N NH₃ Salic



4. Pour 25 mL of sample into a 25-mL graduated mixing cylinder (the prepared sample).

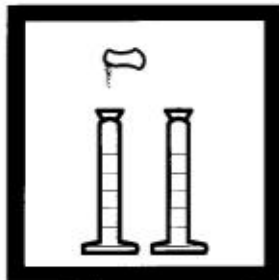
Note: For proof of accuracy, use a 0.20 mg/L NH₃-N solution (preparation given in the Accuracy Check) in place of the sample.

*Adapted from *Clin. Chim. Acta.*, 14 403 (1966)

NITROGEN, AMMONIA, continued



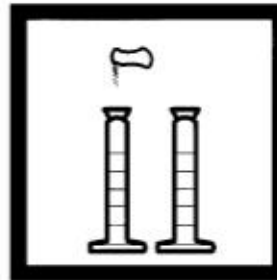
5. Add 25 mL of demineralized water into a second cylinder (the blank).



6. Add the contents of one Ammonia Salicylate Reagent Powder Pillow to each cylinder. Stopper. Shake to dissolve.



7. Press: **SHIFT TIMER**
A 3-minute reaction period will begin.



8. When the timer beeps, add the contents of one Ammonia Cyanurate Reagent Powder Pillow to each cylinder. Stopper. Shake to dissolve.

Note: A green color will develop if ammonia nitrogen is present.

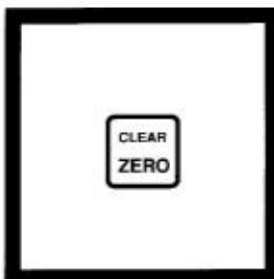


9. Press: **SHIFT TIMER**
A 15-minute reaction period will begin.



10. When the timer beeps, pour the blank into a sample cell. Place the cell into the cell holder. Close the light shield.

Note: The Pour-Thru Cell can be used with this procedure.



11. Press: **ZERO**
The display will show:
WAIT
then:
0.00 mg/l N NH₃ Salic



12. Fill a second cell with the prepared sample. Place the cell into the cell holder. Close the light shield.



13. Press: **READ/ENTER**

The display will show:
WAIT
then the result in mg/L ammonia as nitrogen (NH₃-N) will be displayed.

Note: Results may be expressed as mg/L ammonia (NH₃) or mg/L ammonium (NH₄⁺) by multiplying the above result by 1.22 or by 1.29, respectively.

APPENDIX C: Data interpretation

Soil interpretation (Minbhanan, 2000)

A; Total NITROGEN

- Low: < 0.1% TN
- Medium: 0.1-0.3% TN
- High: > 0.3% TN

B; Organic matter

- Very low <0.75% OM
- Low: 0.75-1.5% OM
- Medium: 1.5-3.0%
- High: 3.0-5.0%
- Very high: >5.0%

C; P₂O₅ in Kg ha⁻¹

- Very low: <10
- Low: 10-30
- Medium 30-55
- High: 55-110
- Very high: >110

D; K₂O in Kg ha⁻¹

- Very low: <55
- Low: 55-110
- Medium: 110-280
- High: 280-500
- Very high: >500

E: pH rating

- Strongly acidic: <4.5
- Moderate acidic: 4.6-5.5
- Slightly acidic: 5.6-6.5
- Nearly neutral: 6.6-7.5
- Moderate alkaline: 7.6-8.0
- Strongly alkaline: >8.5

Table 0.1: Quantities measured in water quality for irrigation

Determination	Symbol	Units ¹	Typical Range
SALINITY			
Total Salt Content:			
Electrical Conductivity	E_{c_w}	dS/m	0 - 3
or			
Total Dissolved Solids	TDS	ppm	0 - 2000
Specific Ions:			
Calcium	Ca^{++}	me/l	0 - 20
Magnesium	Mg^{++}	me/l	0 - 5
Sodium	Na^+	me/l	0 - 40
Carbonate	CO_3^{++}	me/l	0 - 0.1
Bicarbonate	HCO_3^-	me/l	0 - 10
Chloride	Cl^-	me/l	0 - 30
Sulfate	SO_4^{--}	me/l	0 - 20
NUTRIENTS²			
Nitrate - Nitrogen	NO_3-N	ppm	0 - 10
Ammonium - Nitrogen	NH_4-N	ppm	0 - 5
Phosphate-Phosphorus	PO_4-P	ppm	0 - 2
Potassium	K^+	ppm	0 - 2
MISCELLANEOUS			
Boron	B	ppm	0 - 2
Acidity	SAR^3	pH	6.0 - 8.5
Sodium Adsorption Ratio		-	0 - 15

- ¹ dS/m = deciSiemen per meter (equivalent to mmho/cm)
me/l = milliequivalent per liter

² NO_3-N is nitrogen in the form of nitrate. NH_4-N is nitrogen in the form of ammonia. Both may be reported as N.

³ SAR is calculated from the reported Na, Ca and Mg:

$$SAR = \frac{Na}{\left[\frac{\sqrt{Ca + Mg}}{2} \right]}$$

Source:(Roberts-Irrigation Products, 2001)

Table 0.2: Guideline to interpret irrigation water quality report

	Water Quality problem Restriction on Water Use		
	None	Some	Severe
SALINITY (affects plants ability to take up water)			
EC_w (dS/m) or TDS (ppm)	$EC_w < 0.7$ TDS < 450	$0.7 < EC_w < 3.0$ 450 < TDS < 2000	$EC_w > 3.0$ TDS > 2000
INFILTRATION (affects rate water enters soil - use SAR and EC_w)¹			
if SAR _a = 0-3 SAR _a = 3-6 SAR _a = 6-12 SAR _a = 12-20 SAR _a = 20-40	$EC_w > 0.7$ $EC_w > 1.2$ $EC_w > 1.9$ $EC_w > 2.9$ $EC_w > 5.0$	$0.2 < EC_w < 0.7$ $0.3 < EC_w < 1.2$ $0.5 < EC_w < 1.9$ $1.3 < EC_w < 2.9$ $2.9 < EC_w < 5.0$	$EC_w < .2$ $EC_w < .3$ $EC_w < .5$ $EC_w < 1.3$ $EC_w < 2.9$
ION TOXICITY (affects sensitive crops)			
Sodium (SAR) Sodium (me/l) Chloride (me/l) Boron (ppm)	SAR < 3 me/l < 3 me/l < 4 ppm < 0.7	3 < SAR < 9 3 < me/l < 9 4 < me/l < 10 0.7 < ppm < 3	SAR > 9 me/l > 9 me/l > 10 ppm > 3
OTHER EFFECTS (affects sensitive crops)			
Nitrogen, NO ₃ -N (ppm) Bicarbonate, HCO ₃ , me/l	ppm < 5 me/l < 1.5	5 < ppm < 30 1.5 < me/l < 8.5	ppm > 30 me/l > 8.5
PH	Normal Range: 6.5 - 8.5		

¹ High SAR_a accompanied with high EC_w allows water penetration, but is unacceptable for production of salt-sensitive crops.

Source: (Roberts-Irrigation Products, 2001)

APPENDIX D: Ammonia loss computation

Table 0.1: Ammonia loss computations Feb 13

Time [hr]	Ammonia solution basin- reference block							Percentage loss	Effluent Conc- Trap [mgN/L]	Effluent - Ammonia in Basin [mg]	Effluent ammonia Loss [mg]	bucket Irrigation - Trap conc [mgN/L]	Bucket irrigation- Ammonia [mg]	Bucket Irrigation- Ammonia loss [mg]
	Volume of Donic acid in trap [l]	Ammonia solution basin in [mgN/l]	Weight of Ammonia in the basin [mg]	Ammonia Loss [mg]	Volume in Reference basin [l]	Ammonia Concentration in the trapper [mgN/L]	Trap of ammonia at reference field [mg]							
0	0.10	3700	151700	0	41.00	0.00	0.00	0.00	0.000	0.00	0.00	0.00	0.000	
1	0.10	3200	124800	26900	39.00	1.00	0.10	0.000	0.00	0.000	0.00	0.00	0.000	
2	0.09	2800	106120	18680	37.90	9.00	0.81	0.001	0.00	0.000	0.00	0.00	0.000	0.00
3	0.08	2400	86880	19240	36.20	15.00	1.20	0.005	0.00	0.000	0.00	0.00	0.000	0.00
4	0.07	2200	77660	9220	35.30	17.00	1.19	0.013	0.00	0.000	0.00	0.10	0.007	54.24
5	0.06	2100	71610	6050	34.10	24.00	1.44	0.024	0.00	0.000	0.00	0.20	0.012	50.42
6	0.05	2000	67000	4610	33.50	27.00	1.35	0.029	0.00	0.000	0.00	0.30	0.015	51.22
7	0.04	1900	62700	4300	33.00	32.00	1.28	0.030	0.10	0.004	13.44	0.40	0.016	53.75
8	0.03	1700	55420	96280	32.60	33.00	0.99	0.001	1.10	0.033	3209.33	1.60	0.048	4668.12

All blocks had the same volume of urine application

Bucket application- 41 Lts and during the 8hr the loss was	4,668.12 mgN	The loss per area	555.73 mgN/m ²	3.08 %
Micro-irrigation with effluent from reactor 41 Lts the loss was	3,209.33 mgN	The loss per area	291.76 mgN/m ²	2.57 %

Amount of urine used through bucket irrigation

Initial weight 41.00 L x 3700 mg/L = 151700 mg

The ammonia loss was 3934.9 mg

Bucket Urine applied	151700 mg	-	4668.12 mg	=	147031.9 mg N	retain in the field	96.92 %
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Effluent applied through micro-irrigation

Micro	151700 mg	-	3209.33 mg	=	148490.7 mg N	retain in the field	97.88 %
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Table 0.2: Ammonia loss computations Feb 18

Time [hr]	Ammonia solution basin- reference block									Percentage loss	effluent Conc- Trap [mgN/L]	Effluent - Ammonia in Boric [mg]	Effluent ammonia Loss [mg]	bucket Irrigation - Trap conc [mgN/L]	Bucket irrigation- Ammonia [mg]	Bucket Irrigation- Ammonia loss [mg]
	Volume of Boric acid in trap [L] Effluent & Bucket	Volume of Boric acid in trap [L] in Reference point	Ammonia solution basin n [mgN/L]	Weight of Ammonia in the basin [mg]	Ammonia Loss [mg]	Volume in Reference basin [L]	Ammonia Concentration in the trapper [mgN/L]	Trap of ammonia at reference field [mg]								
0	0.10	0.115	3600	162000	0	45.00	0.00	0.00		0.00	0.000	0.00	0.00	0.00		
1	0.10	0.115	3400	141780	20220	41.70	2.00	0.23	0.001	0.00	0.000	0.00	0.60	0.060		
2	0.09	0.105	3100	127720	14060	41.20	5.00	0.53	0.004	0.10	0.009	241.03	1.30	0.117	3133.37	
3	0.08	0.095	3000	120000	7720	40.00	8.00	0.76	0.010	0.30	0.024	243.79	1.70	0.136	1381.47	
4	0.07	0.085	2900	111940	8060	38.60	12.00	1.02	0.013	0.60	0.042	331.88	2.00	0.140	1106.27	
5	0.06	0.075	2800	105000	6940	37.50	16.00	1.20	0.017	0.70	0.042	242.90	2.70	0.162	936.90	
6	0.05	0.045	2600	94380	10520	36.30	19.00	0.86	0.008	1.10	0.055	683.16	3.20	0.160	1987.37	
7	0.04	0.035	2500	87250	7130	34.90	22.00	0.77	0.011	1.20	0.048	444.47	4.10	0.164	1518.60	
8	0.03	0.025	2400	81840	80160	34.10	24.00	0.60	0.001	1.60	0.048	6412.80	4.40	0.132	17635.20	

All blocks had the same volume of urine application

Bucket application- 45 Lts and during the 8hr the loss was	17,635.20 mgN	The loss per area	2,099.43 mgN/m ²	10.89 %
Micro-irrigation with effluent from reactor 45 Lts the loss was	6,412.80 mgN	The loss per area	582.98 mgN/m ²	4.52 %

Initial weight Amount of urine used through bucket irrigation
 45.00 L x 3500 mg/L = 162000 mg

The ammonia loss was 3934.9 mg

Bucket Urine applied 162000 mg - 17635.20 mg = 144364.80 mg N retain in the field 89.11407 %

Effluent applied through micro-irrigation
 Micro 162000 mg - 6412.80 mg = 155587.20 mg N retain in the field 96.04148 %

APPENDIX F: Ammonia Volatilization bucket and drip effluent application

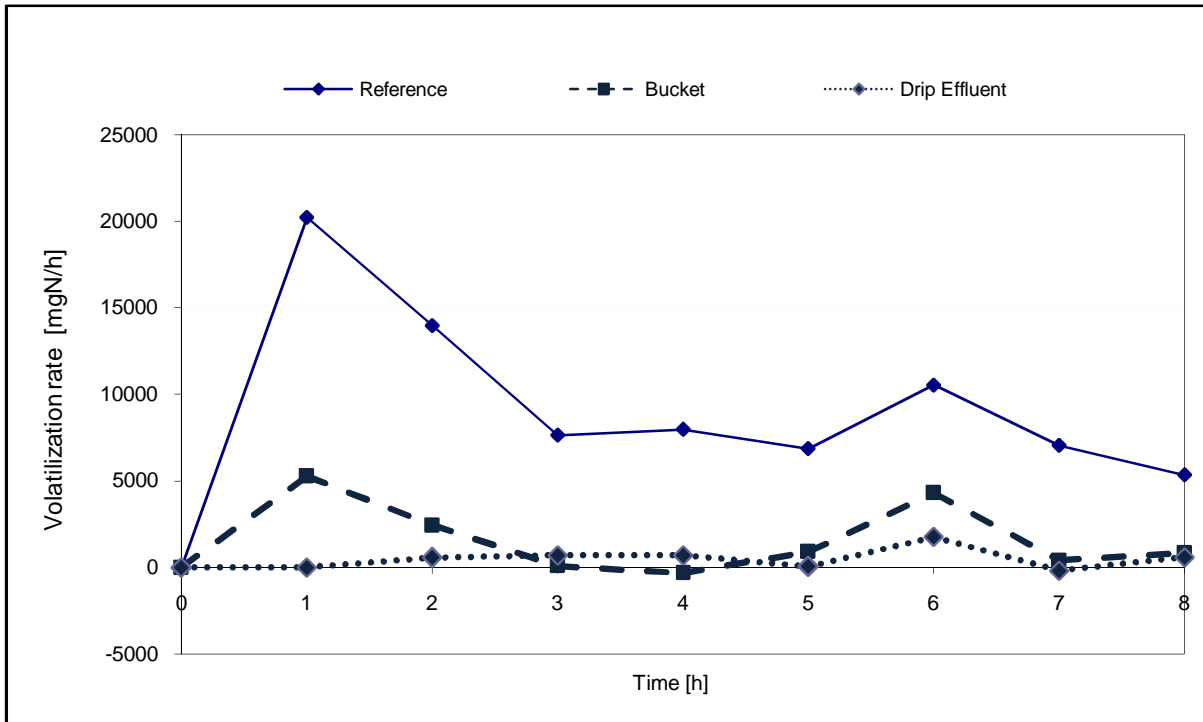


Figure 0.1: Volatilization rate bucket and drip effluent 18/02/2009

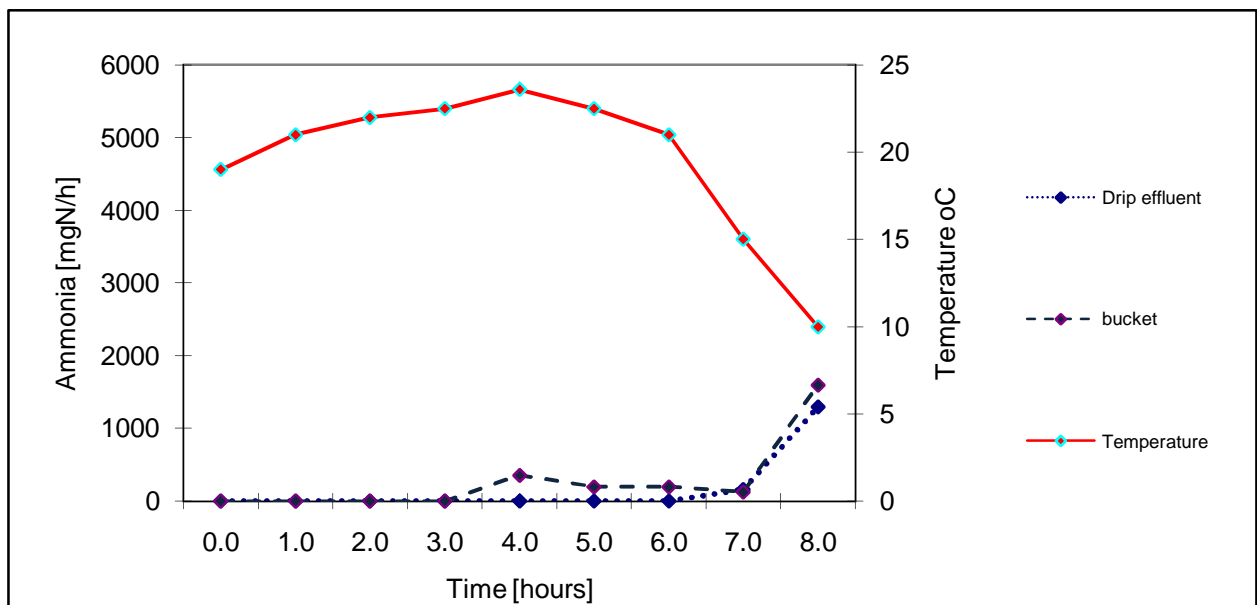


Figure 0.2: Volatilization rate bucket and drip effluent (temperature effect)

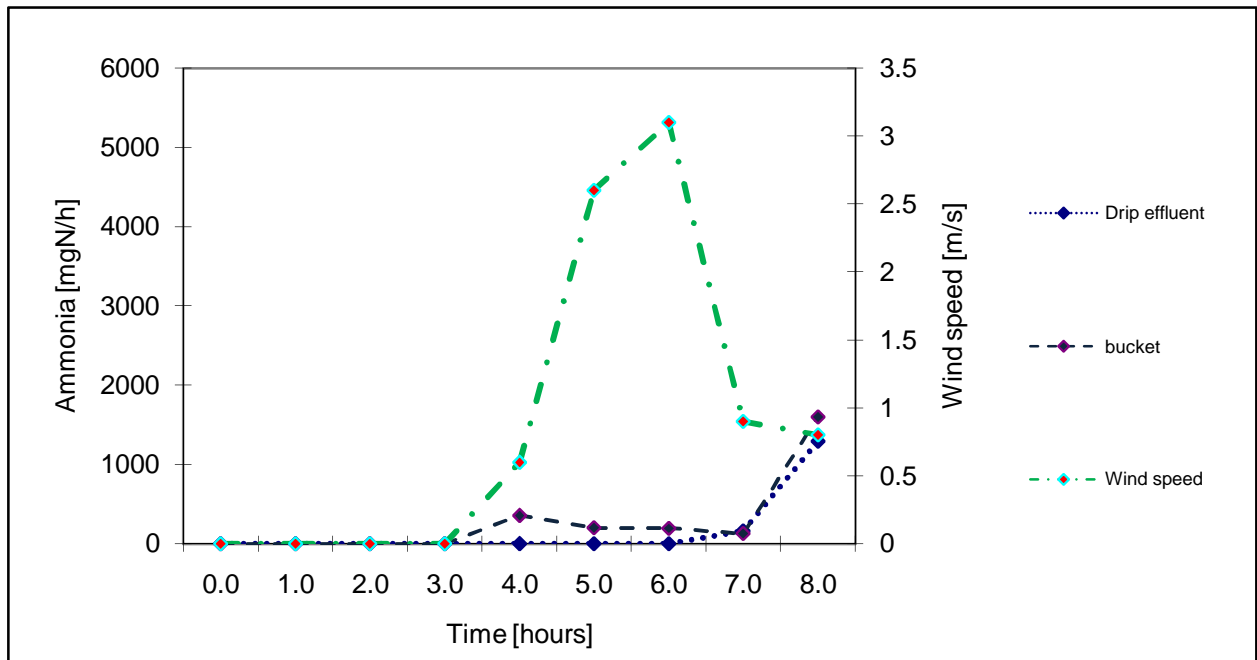


Figure 0.3: Volatilization rate bucket and drip effluent (Wind effect)

APPENDIX E: Drip irrigation head measurements

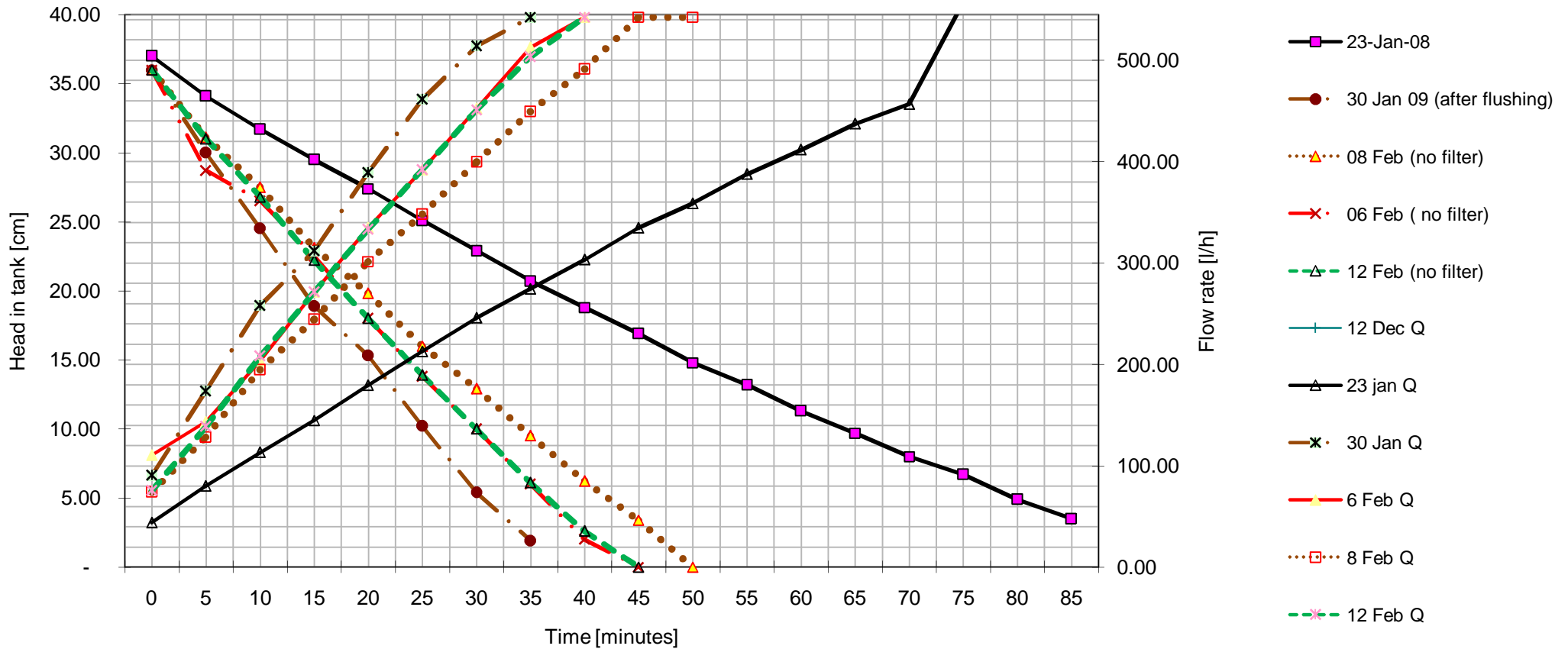


Figure E: 1 Water application through drip irrigation- Head measurements

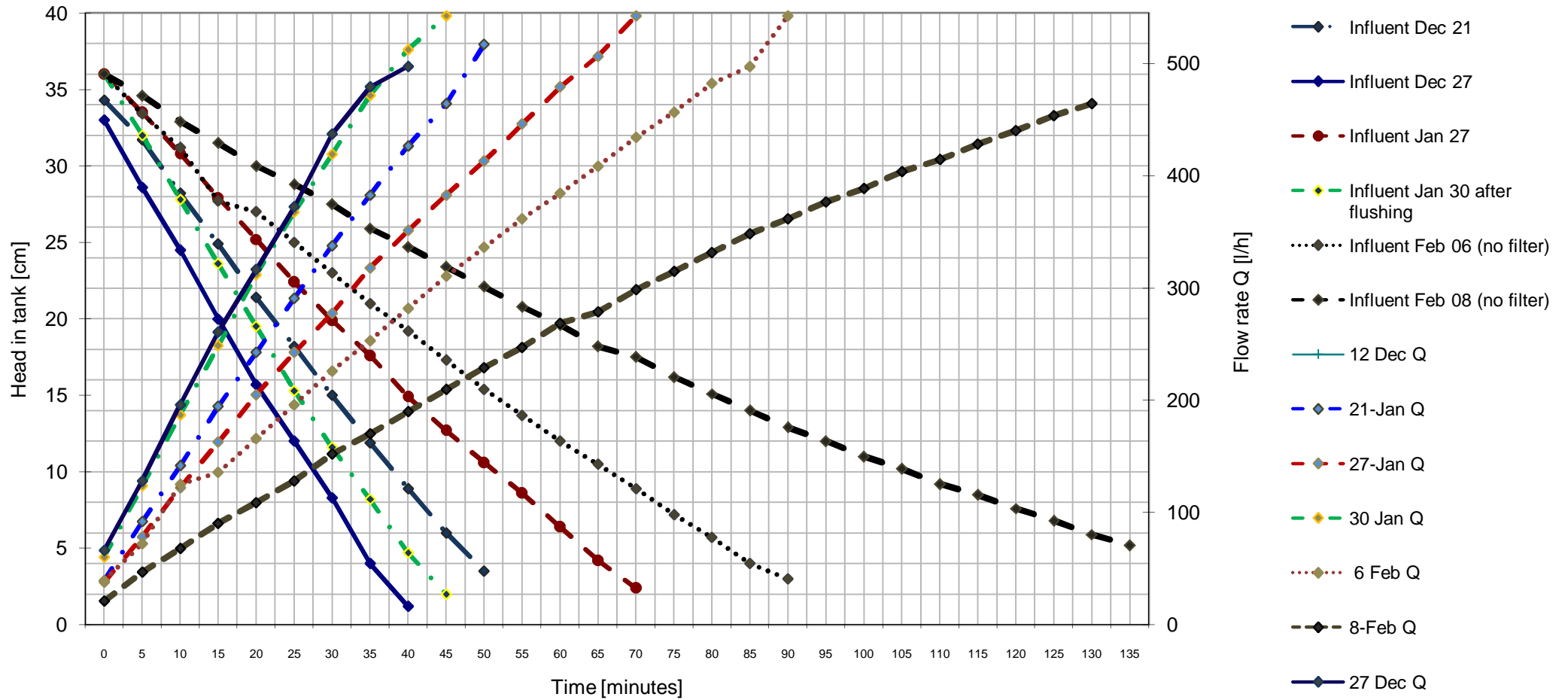


Figure E: 2: Influent application head measurements

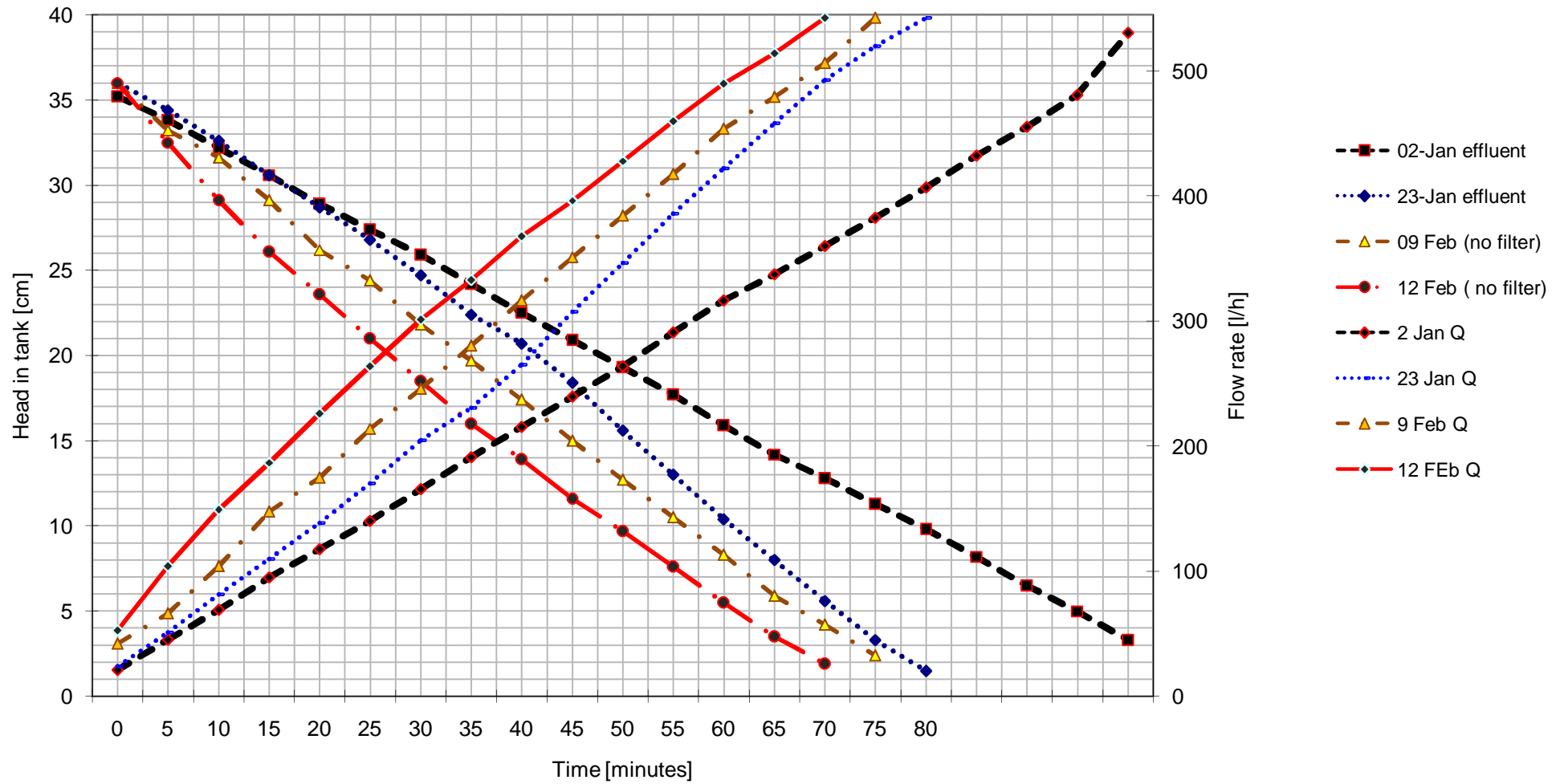


Figure E: 3 Effluent application head measurements

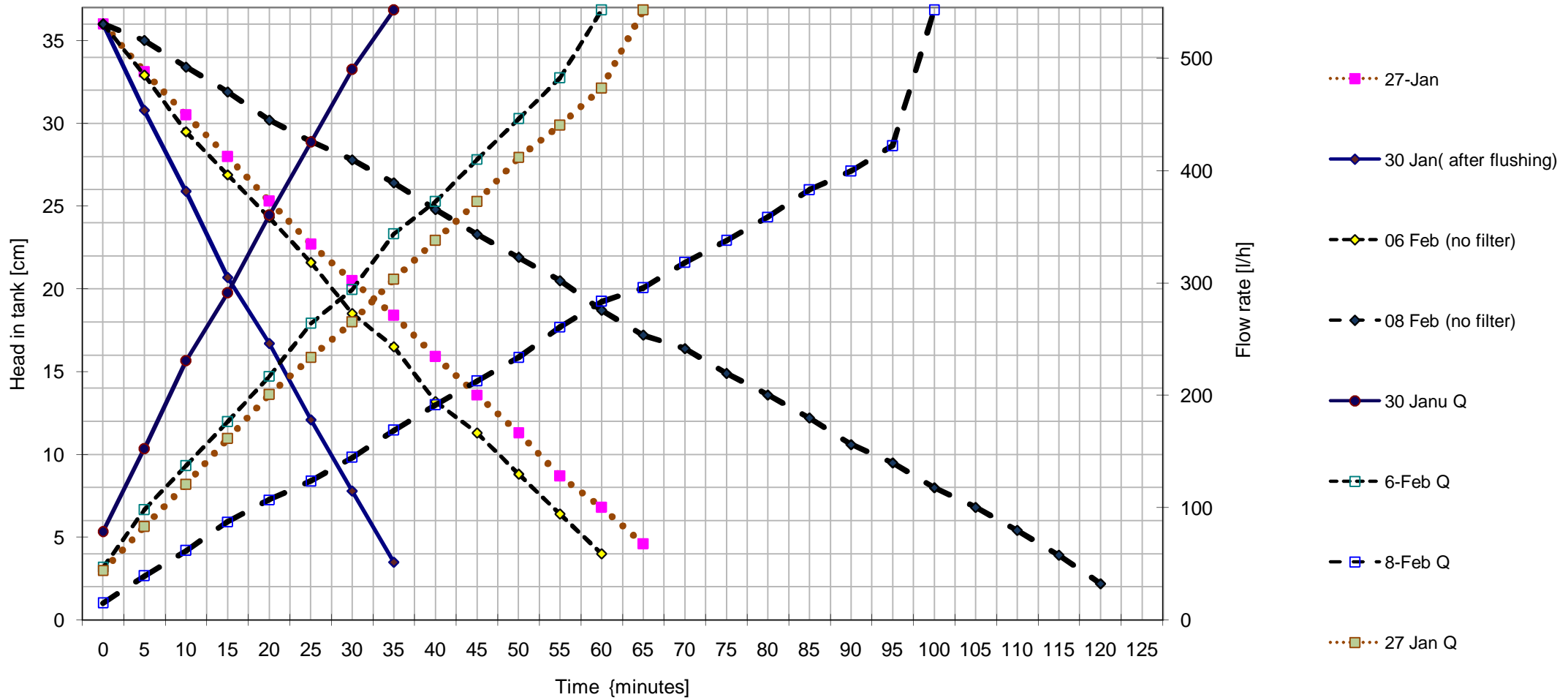


Figure E: 4 Diluted influent head measurements

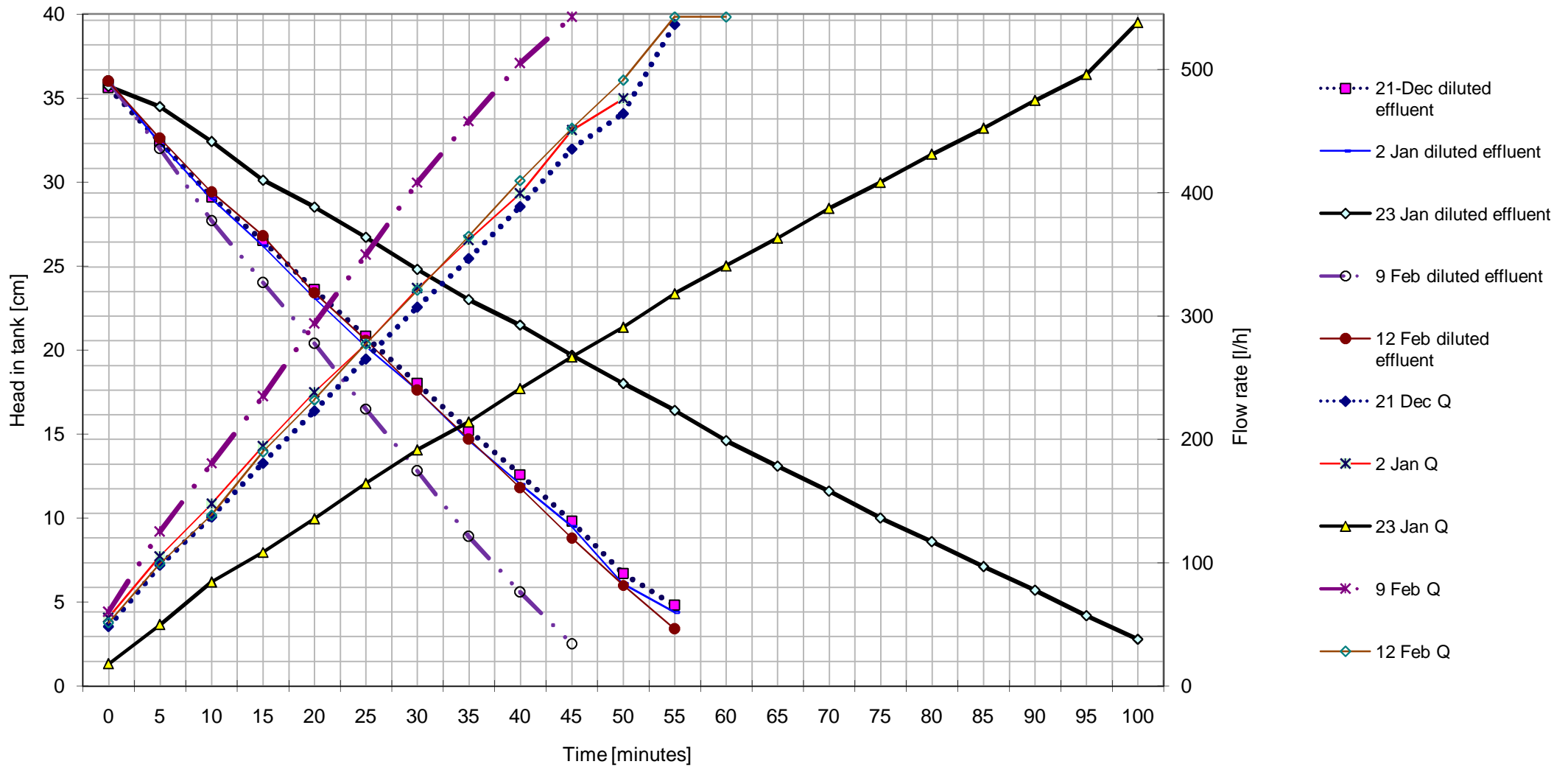


Figure E: 5 Diluted effluent application- drip system- Head measurements

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