EXPERIMENTS ON STRUVITE PRECIPITATION, APPLICATION AND ECONOMIC ANALYSIS IN ARBA MINCH, EHTIOPIA

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ABSTRACT

Source-separated urine from UDDTs (Urine-Diversion Dry Toilets) is a potential source of nutrients so as to be used as a substituent of commercial fertilizer. However, collection, storage and transportation of urine are significant problems in Arba Minch. To counteract the arising problem to deal with urine used for closing the loop of sanitation products and agriculture, struvite precipitation is proposed to be a good solution. EAWAG's experiences in Nepal, revealed that fresh and stored urine quality is significantly different i.e. urine hygenization leads to considerable nutrient loss. Moreover, depletion of phosphorus which potentially leads to global phosphorus insecurity should be addressed by proper nutrient recycling technological option.

The aim of the experiments in Arba Minch is to test EAWAG's experiences under Ethiopian conditions. Running the field experiment is very essential for Arba Minch because of the availability of UDDTs in the town which offers the possibility to check the production potential of struvite as well as its application in three different possible ways. Additionally, an economic analysis will be completed in order to check the economic feasibility of the struvite in local conditions.

The work plan for the experiments is as described below:
Urine quality analysis (fresh urine; age and gender wise & stored urine from the tank); [April, 2012], Struvite precipitation; schedule: [April – June, 2012],
Micro tube drip irrigation application on crop (maize) in the following possible combinations & number of trials
Combined application of struvite and effluent, commercial fertilizer, control. Monitoring crop growth
Compare: crop yield Schedule: [Nov – Dec, 2012]
Feasibility analysis; schedule: [Nov– Feb, 2012]

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INTRODUCTION/BACKGROUND

Source-separating toilets were introduced in Arba Minch with the beginning of ROSA project in 2006. UDDTs were well demonstrated in pilot plants during the period and widely implemented by linking the Arba Minch town sanitation policy with the SPA programme. Currently, there is greater demand for UDDTs from a number of households in the town. This clearly indicates the potential availability and acceptance of such type of toilet in Arba Minch.

Studies or experimental works done in Arba Minch during the ROSA project showed that nutrients could be recovered from human urine. Urine was applied to maize in the proportion of three litres of water to one litre of urine. Urine from UDDT toilets was transported to the Arba Minch University research and demonstration site where the trial experiments were done. Urine separation is a well-known option to generate locally available natural fertilizers. However, the practiced methods of storage for self hygenization led to a significant nitrogen loss.

One of the essential macro nutrients found in urine which is important for the plant growth is phosphorous. In addition, the element phosphorus is contained in phosphorus ore deposits all over the world. Nevertheless, the only significant global resource of phosphorus, rock phosphate, is concentrated in a limited number of places. Scientific studies show that the element phosphorous will be depleted after 100 years unless recovery technologies are applied. Serious environmental problems caused by phosphorous pollution, such as from urine and rapid depletion of global phosphorous reserves can be tackled by recovering recycling phosphorous losses by applying urine conditioning technologies that need to be adapted to local conditions. Additionally, the reduced volume after conditioning makes transport and handling for farmers easier. Urine conditioning technologies (such as production of struvite from urine) could be adapted in Arba Minch condition.

Struvite is a white crystalline powder, consisting of equi-molar amounts of ammonium, magnesium and phosphate and 6 hydration molecules ($MgNH_4PO4{\cdot}6H_2O$). It precipitates spontaneously in hydrolysed urine, which has an elevated pH of 9. Addition of magnesium causes struvite precipitation, leading to a phosphorus removal. Struvite precipitation was shown to be a robust and effective method to recover phosphorus from urine. The product does not form a hazard for public health with respect to heavy metals and micro pollutants. The economic feasibility of struvite production at household level was checked in Nepal and resulted not feasible. However, this would be checked at community level in Arba Minch.

PROBLEM STATEMENT

Researches revealed that urine has a potential for nutrient recycling. However, the practiced methods of urine storage for self hygenization lead to a significant nitrogen loss and the cost of bulk volume of urine transportation and handling is the other additional real problem. Moreover, depletion of phosphorus, which potentially leads to global phosphorus insecurity, should be addressed by proper nutrient recycling technological option.

OBJECTIVE

Struvite precipitation, application, and demonstration of individual and combined effect of struvite & effluent, and economic analysis

Specific objectives:

- To analyze fresh and stored urine quality collected from UDDT users
- To check the process efficiency (precipitation and recovery) of phosphate from urine solution
- To evaluate the effect of struvite, struvite & effluent, and artificial fertilizer with MTDI system through monitoring the growth and yield of maize
- To check the adaptability and economic feasibility under local conditions

SIGNIFICANCE

Improvement in soil conditioning and better nutrient recovery from waste; reduction in loss of nitrogen from urine in the form of ammonia by urine conditioning (Struvite generation), better phosphorus concentration will be achieved as well as ease of storage, transport and handling

LITERATURE REVIEW

Phosphorus cycle

Phosphorus is an essential nutrient for plants and animals in the form of ions PO_4^{3-} and HPO_4^{2-}. It is a part of DNA-molecules, of molecules that store energy (ATP and ADP) and of fats of cell membranes. Phosphorus is also a building block of certain parts of the human and animal body, such as bones and teeth. The element phosphorus is contained in phosphorus ore deposits all over the world. Yet, the only significant global resource of phosphorus, rock phosphate, is concentrated in a limited number of places. Rock phosphate is a general term for rock that contains a high concentration of phosphate minerals, commonly belonging to the apatite group (Valsami Jones, 2004). In the natural environment, the phosphorus cycle starts with the release of phosphate minerals through rock weathering. Through the process of erosion, inorganic phosphate moves to soil and rivers, where it is absorbed by plants and incorporated into organic molecules, such as ATP or phospholipids. By ingestion phosphorus travels up the food chain. It is returned to the environment in the form of excreta and broken down cell tissue. Through washout it ends up in sediments of rivers and eventually oceans (Figure 1). This cycle takes 10^7 - 10^8 years before the deposits are transformed into phosphate rock and brought back to the surface (Den Haag, 2008). Phosphate mineral rock is therefore regarded as a **non-renewable and limited resource**. Considering its indispensability for food production and therefore human life, it is essential that we look for sustainable phosphorus recovery methods.

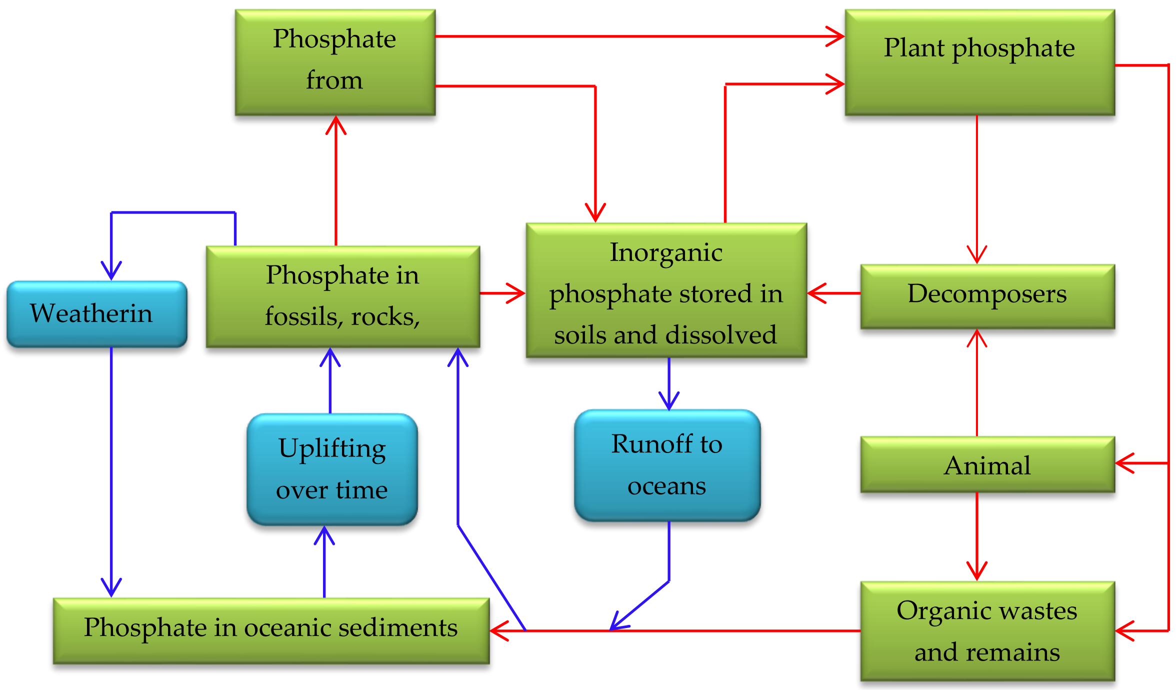

Figure 1 - A schematic representation of the phosphorus cycle (source: Lenntech BV)*L*

MATERIALS AND METHODS

Urine collection and transportation

According to the demand for urine by AMU for struvite production, Wubet le Arba Minch solid waste collectors association collects and transports source-separated urine to Egnan New Mayet (ENM) compost producing association site where struvite reactor is installed. Due to the long distance (8km) from upper town to the site, fifty birr per individual as a sort of motivation is paid for the trip; three workers from the association are considered in each trip.

Urine quality analysis

Electro-photometer is used for urine quality analysis (both fresh and stored). Appropriate reagents were used for analysing important parameters, such as pH, EC, PO_4-P, NH_4-N, Ca^{2+} and Mg^{2+}.

Struvite reactor

It was sub-contracted to the mechanical engineering department in the university. The component parts of the reactor are stainless steel vessel, stand, ladder, stirrer, valve, and filter bag (Figure 2). Parts are made out of galvanized iron sheet metal, angle iron, solid iron, plastic pipe, nylon and ball valve. The reactor drawings and all the specifications are adapted from Nepal's experience and are of public domain.

a. Reactor b. Stirrer c. Valve d. Filter bag

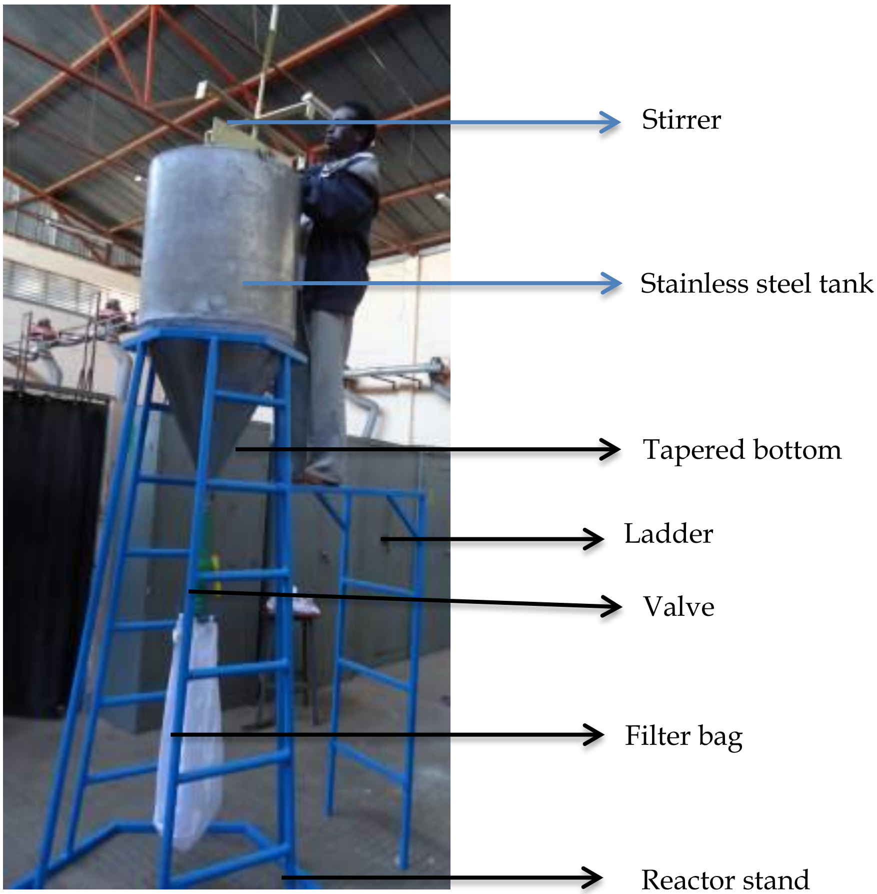

Figure 2 - Struvite reactor by CLARA_AMU

Struvite production

The urine is being collected by solid waste collectors association and transported to ENM original compost site where the reactor is installed. The stored urine sample quality was analysed by electro photometer. Based on the phosphate concentration determined in the laboratory and the trial molarity of Mg:PO_4-P, the amount of magnesium required is calculated and measured by electric balance for the specified volume of the urine in a batch reactor.

Figure 3 - Photos taken during the mixing of the solution (stored urine plus MgO)

The mixing time adapted was 15 minutes. The filtration takes two to three hours and the precipitate was exposed to sun for drying. It takes an average of three to four days for complete dry up under Arba Minch climatic conditions. There was a number of trial molarity ratios used to improve the phosphate recovery efficiency. (1:1, 1.2:1, 1.5:1 and 1.8:1)

Crop trial protocols

The area of experiment is 11m x 5.60m. It is subdivided into three small trial plots where application of artificial fertilizer, struvite and effluent and control would be tested.

Figure 4- Plot preparation with MTDI system

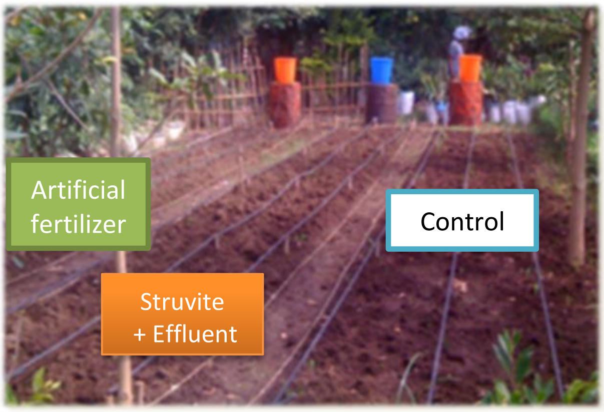

Figure 5 - Photo of the crop trial plot with MTDI system at ENM research & Demo site

The small plots are used for testing artificial, organic fertilizers and control comparatively in terms of crop yield and growth. The micro tube drip irrigation system is used for all trials based on the crop water requirement. Irrigation water is scheduled in two days interval in all stages of crop growth in average bases.

Fertilizer application

Figure 6 - Artificial fertilizer (P_2O_5) application and struvite application

Figure 7 - Effluent application on the second plot

ECONOMIC ANALYSIS

The aim is to check whether local capacities are to be tailored with struvite generation technology or not. All costs of material and labour would be put in money terms and checked for its economic feasibility in Arba Minch situation.

RESULT AND DISCUSSION

Fresh and stored urine quality analysis result

Table 1- Average concentration of selected compounds in fresh urine (12 samples, 6 male, 6 female, ages between 6 and 64) and stored urine from UDDT tanks (13 samples) in Arba Minch, Ethiopia

		Fresh urine			Stored urine		
Parameter	Unit	Avg	STD	Median	Avg	STD	Median
pH		5.50	1.05	5.63	8.6	0.09	8.6
EC	mS/cm	15.39	3.63	15.28	28.76	4.25	29.10
PO_4-P	mg/l	714.85	285.56	856.28	293.35	74.97	289.87
NH_4-N	mg/l	795.45	418.93	790.00			
Cl^-	mg/l	5778.70	2246.13	5640.28			

K^+	mg/l	2644.89	1032.63	2668.90
Na^+	mg/l	3813.65	1766.75	3461.40
Total Carbonate	mg/l	2221.21	586.13	2350.00
Ca^{2+}	mg/l	55.79	26.34	54.11
Mg^{2+}	mg/l	155.35	70.25	146.47
SO_4^{2+}	mg/l	23.90	9.35	26.00

Storage increases the pH of urine; spontaneous precipitation occurs due to storage time and completely consumes calcium and magnesium available; volatility of ammonia reduces the concentration of ammonium nitrogen.

Estimation of phosphate concentration in stored urine

In struvite production, the phosphate concentration in the process influent (i.e. urine) must be known as exactly as possible in order to facilitate an optimal magnesium dosage. Estimating the phosphate concentration is also needed for accurate financial compensation for urine deliveries. Since electrical conductivity measurements have proven to be a rapid and cost-efficient tool for online phosphate monitoring in biological processes (Wylie, 2009; Maurer and Gujer, 1995), we adapted the method for the use with urine. The temperature compensated electrical conductivity (25°C) and phosphate concentration were determined in ten samples of stored urine and plotted against each other. The samples originated from the storage tanks of different UDDTs in Arba Minch and were taken during the 4 months field research. The results (Figure 8 -) show a very good correlation ($r^2 = 0.9$). Within the measured range, the phosphorus content can be estimated using the following formula:

$$[PO_4 - P] = 16.72 * EC_{25°C} - 187.53 \quad [1]$$

where the temperature compensated electrical conductivity $EC_{25°C}$ is measured in mS/cm and the phosphate concentration $[PO_4\text{-}P]$ is given in $mgPL^{-1}$.

For the samples analysed (phosphate concentrations were between 209.9 and 472.0 $mgPL^{-1}$), the standard deviation for the determination of phosphate via electrical conductivity was 24.89 $mgPL^{-1}$ with respect to the photo-spectrometric analysis. This standard deviation is considerably lower than the standard deviation determined for the average phosphate concentration without linear correlation (74.97 $mgPL^{-1}$, see Table 1), which means that estimating the phosphate concentration with Equation 1 results in a significantly more accurate value than just using the average phosphate concentration.

Estimating the phosphate concentration via electrical conductivity has important advantages over the direct chemical determination of phosphate: it delivers an instantaneous result, it is much cheaper and it does not require careful handling of chemicals. However, the correlation between phosphate and electrical conductivity should be validated for every community anew to account for differences in the urine collection (e.g. composition changes due to ammonia volatilization).

Table 2 - Correlation between compensated electric conductivity and phosphate concentration

$EC_{25°C}$	37.56	29.10	29.47	30.42	31.98	35.25	29.23	25.11	26.75	25.19	23.82	25.31	24.65
PO_4-P	472.07	323.59	289.87	317.06	308.36	372.54	337.73	223.53	269.21	255.07	209.93	210.47	224.07

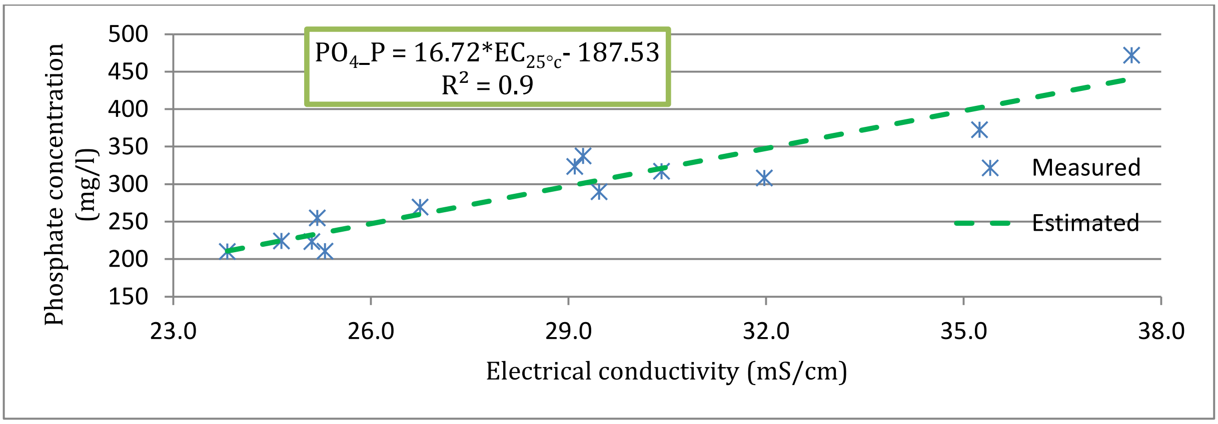

Figure 8 - Correlation between compensated electric conductivity and phosphate concentration

Struvite generated in batch mode

Figure 9 - Struvite precipitate exposed to sun light and dried struvite in a glass bottle

Table 3 - struvite production efficiency with respect to various molarity of Mg : PO4-P

B.No	Molar ratio	Urine (liters)	Mg (gm)	MgO (gm)	Struvite (gm)	Input PO_4-P conc.	Effluent PO_4-P conc.	PO_4-P recovery % efficiency
1	1 : 1	20	5.616	14. 04	31.09	---	---	---
2	1.5 : 1	40	21.73	54.32	102.00	260	797.02	67.31%
3	1.8 : 1	40	26.07	65.18	105.69	701.58	232.22	66.90%

The phosphorous recovery efficiency of struvite production in most literature is more than ninety present (> 90%) for molar ratio of Mg to phosphate ranging from 1:1 to 1.8:1. However, the phosphate recovery efficiency in this experiment resulted to be low (66.9%). To increase the recovery efficiency of phosphate from urine, process parameters should be investigated. These parameters are pH, temperature, stirrer type, filtration on phosphorous removal efficiency and average crystal size of the precipitate. In our experiment the pH, mixing time, temperature of the solution, and type of stirrer were within the required range. The type of filter used has no pore size specification. Standard filter bags were not available at national markets on top of this; local material is convenient to adapt the technology to local business groups. As it was observed during the filtration time, very fine precipitates could not be retained in the filter bag. Hence, the low process efficiency of the struvite production in general and filtration process efficiency in particular is due to the filter type used.

Crop growth and yield

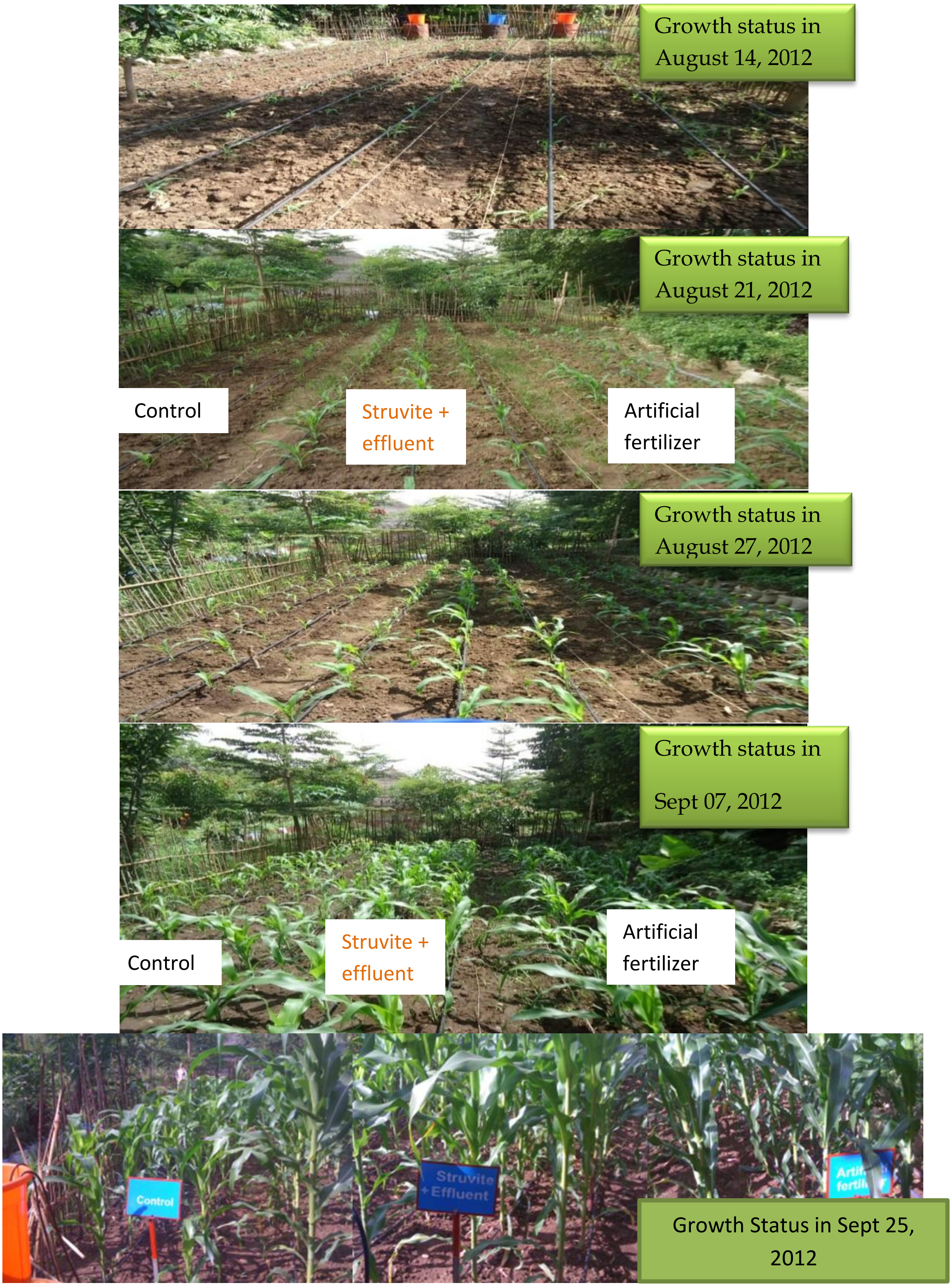

Figure 10 - The growth status of maize through time

Phosphorous is one of the essential macro nutrients required for plant growth. The experiment with maize crops is to investigate the response of maize to the application of struvite and to confirm the value of this material as a source of phosphorous. The growth status of maize is one of the basic parameters to compare the effect of phosphate from struvite and artificial fertilizer on the crop. From the above pictures, the growth status in terms of leaf diameter and height is similar for the first two conditions and quite different from the growth status in the control one. This clearly shows that struvite performs comparably to Di-ammonium phosphate (DAP) fertilizer as a source of phosphorous.

CONCLUSION & RECOMMENDATIONS

The phosphate recovery efficiency results to be low. This is due to the process efficiency of the struvite production in general and filtration process efficiency in particular.

Growth status of the experimental trials completely revealed that application of DAP with urea, struvite and effluent, and the control have got differences in growth and clear differences in colour. The above stated variations in the current status are also an indicator for probable change in yield in future.

The recommendation that would be very important here is that to attain good filtration efficiency there has to be appropriate filter pore size selected to develop a blanket of filter cake that potentially reduces the outgoing phosphate concentration along with the effluent. The purity level of struvite, test for heavy metals and coli-form should be further analysed.

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