

Impact of rockphosphate and farmyard manure on the fertilising effect of human urine (ECOSAN) in cotton culture in the West-African Sahel

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by

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Acknowledgements

This thesis is the result of a field trial implemented during a four month internship in Mali. The internship was performed in cooperation with the CREPA (*Centre Régional pour l'Eau Potable et l'Assainissement à faible coût*) headquarters in Burkina Faso.

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I appreciate the support of the responsible persons of the CREPA and the IPR/IFRA, because without them the implementation of the experiment would not have been possible.

In Germany a warming "thank you" goes to Prof. Engels, Dr. Horlacher, Paula and my family.

It must be said, though, that the significance and scientific value of the experiment unfortunately has been limited by the fact that a lot of important results have not been available until the completion of this thesis (more than a year after the set up of the field trial).

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Executive Summary

This work has been performed in order to investigate the fertilising effect of human urine when applied during the dry season in the regional context of the West-African Sahel. This investigation has been carried out because an application of urine during the dry season would lessen the need for storage capacity and even out work peaks, on condition that the nutrients are stored in the soil.

The experiment was performed as a three-factorial trial: treatments with no application of urine, superficial application or application with incorporation into the soil were installed. Additionally, combinations with farmyard manure, rockphosphate and with both together were tested. Yield in cotton culture was investigated and soil samples were taken in the first month after application in order to determine the nitrogen content (N_{tot}), the content of organic matter and the pH-value.

The yield results document the fertilising effect of urine. It can be surely stated that an application of urine does improve the yield, even when applied already ahead of the growing season. When immediately incorporated, the fertilising effect of urine is improved. A combination with rockphosphate and farmyard manure brought slightly higher yields, which was not significant, though. As further results of soil sampling and N-uptake of plants were not available, it is difficult to describe the N-dynamics in the soil after an application of urine during the dry season.

The available results do not suffice to assess if an application during the dry season has clear disadvantages compared to an application before sowing. In the results, a trend becomes apparent that no significant nitrogen losses appear until the onset of the rainy season. This trend is confirmed by previous experiments. Contrary to the hypothesis proposed in the experiment, no biological immobilisation during the dry season is to be expected. Due to the high pH-value of the urine the pH in the soil increases after an application. This is a spatially and temporally limited process, though.

Further experiments and different measurements are necessary in order to answer the questions formulated in this experiment more satisfactorily.

1. Introduction

2.6 billion people on earth do not have access to improved sanitation. This poses a serious threat to their health as well as to the environment. At the same time valuable nutrients contained in human excreta are lost. ECOSAN (“ecological sanitation”) is an approach trying to solve these problems. Key elements of this approach are: prevention of pollution of the valuable resource water, hygienisation of human excreta and their reuse as fertiliser in agriculture. While technical and organisational aspects of this approach are often stressed, little detailed information is available on the reuse aspects.

The general issue covered in this work is optimising application. The general advice, as given by JÖN SON et al. (2004), is to apply urine close to the time of sowing. But the urine accumulates during the whole year. Therefore, if the urine has to be stored until the vegetation period, this can be a severe challenge for storing capacity. In regions where a dry season lies between the vegetation periods (as it is the case in many tropical and subtropical countries), a storage of nutrients in the soil during the dry season might be an interesting option. This would lessen the need for storage capacity and even out work peaks at the same time. But as JÖN SON et al. point out, there are very few findings that show to what extent losses of nitrogen have to be expected if urine is applied already during the dry season.

2. Aims of this thesis

The purpose of the field-trial performed for this thesis was to obtain further insights regarding the possibility of applying human urine as plant fertiliser during the dry season. The storage of nitrogen in the soil after application of urine and the fertilising effect of urine in cotton-culture was investigated. Additionally, an examination whether the addition of rockphosphate and farmyard manure improves the storage of nitrogen in the soil and its fertilising effect, was performed.

The hypothesis proposed in this trial was that the storage of nitrogen of the urine in the soil would be favoured by temporal biological immobilisation via microorganisms. Although a reduced microbial activity during the dry season must be expected, this activity is not disrupted completely (WICK 1997, AUGUSTINE & McNAUGHTON 2004, SHAHANDEH et al. 2004). It was supposed that the addition of organic matter, a wide C/N ratio assumed, stimulates microbial growth and therefore temporal immobilisation of nitrogen (see TREHAN

& WILD 1993, SCHEFFER & SCHACHTSCHABEL 2002, SØRENSEN 2004). BABANA & ANTOUN (2005) describe the existence of microorganisms in soils of Mali that can solubilise rockphosphate and integrate it into their biomass. Hence, the assumption was derived that the application of rockphosphate could stimulate the growth of these microorganisms, and therefore their uptake of nitrogen. Furthermore, the provision of phosphorous (the easy available fraction of the rockphosphate and phosphorous released by the phosphorous solubilising microorganisms) could stimulate growth of other microorganisms for which the availability of phosphorous in the soil acts as a limiting factor (ILSTEDT & SINGH 2004).

3. Material and Methods

The field-trial was performed on behalf of the CREPA (*Centre Régional pour l'Eau Potable et l'Assainissement à faible coût – regional centre for potable water and low-cost wastwatertreatment*) in cooperation with the IPR/IFRA in Mali.

Geography and climate on experimental site

The institute is located in the north-Sudanese climate zone which is characterised by yearly precipitation of 700 mm – 1300 mm, a rainy season lasting 4 – 6 months, savannah as type of vegetation and a classification as “tropical dry forest” (according to FAO – eco-zones).

The exact geographical location is 12°56” northern latitude and 7°32” western longitude. The institute is located 326 m above N.N.

The climate in Mali is characterised by a dry season lasting from October until the end of May, and a rainy season lasting from June until begin of October, with maximal precipitation in August. Yearly precipitation lies between 700 and 900 mm, 743 mm in average, in the year 2006 precipitation was 764 mm.

Soils

No soil-profile was prepared on site. The French classification of the soils runs as follows: *sols ferrugineux tropicaux rubéfiés*, *sols ferrugineux tropicaux jaunes*, *sols hydromorphes à amphigley* and *sols ferrugineux à hydromorphie profonde*. Without any detailed knowledge about the soil’s properties on site it is not possible to translate the french classification to the

current FAO-classification. Classifications from Set 6 “*Mineral Soils conditioned by a wet (sub)tropical climate*”, for example Lixislos, come into consideration.

An analysis of soil-texture (from 0 – 30cm) has been performed for every parcel in the field trial. The content of clay ranges between 7 and 12 % (mean 9.3%), silt content ranges from 35 to 45 % (mean 37.3%) and sand content ranges from 43 to 68% (mean 53.3 %). According to BODENKUNDLICHE KATIERANLEITUNG (1994) the soil texture classifies as medium loamy sand (SI3) up to silty-loamy sand (Slu).

Experimental setting

Aiming to examine interactions between the different components applied, the experiment was performed as a three-factorial trial. The first factor was represented by the application of urine: no application, superficial application, application with incorporation into the soil. The combination with farmyard manure was chosen as the second factor: application of farmyard manure, no application. Third Factor was the application of rockphosphate (application/no application). The combination of all factors resulted in 12 different treatments, as they are shown in Table 1.

Tab.1 Presentation of treatments of the trial

Treatment	Application	Abbreviation
I	No application	n.a.
II	Urine, superficial	Us
III	Urine, incorporated	Ut
IV	rockphosphate	P
V	Farmyard manure (organic matter)	OM
VI	Urine, superficial + rockphosphate	Us + P
VII	Urine, superficial + Farmyard manure	Us + OM
VIII	Farmyard manure + rockphosphate	OM + P
IX	Urine, superficial + Farmyard manure + rockphosphate	Us + OM + P
X	Urine, incorporated + rockphosphate	Ut + P
XI	Urine, incorporated + Farmyard manure	Ut + OM
XII	Urine, incorporated + Farmyard manure + rockphosphate	Ut + OM + P

Each treatment was installed in four repetitions. This led to a trial with 48 parcels, which have been set up in a randomized block design (design of the experimental setting see Fig.A1). Each parcel measured 3.20 m x 4.50 m = 14.4m². Between each parcel 1.00 m distance was left, the distance between each block was 1.50m

Characterisation of the applied substances

The urine was collected in an ECOSAN pilot-project in Fana, a place located in 80 km distance to the experimental site.

Unfortunately, laboratory analyses of the urine and the farmyard manure have not been available until completion of the thesis. Therefore, it was necessary to work with approximate values. The content of nitrogen in the urine was estimated 3.5g/l, based on previous experiments (DEMBELE 2007).

The farmyard manure came from cattle of local peasants. It included a high fraction of straw, due to high crude fibre uptake by the animals during the dry season.

The rockphosphate originated from the mines of Tilemsi in Mali. It is characterised as an carbonate-apatite-rock and is available in the form of a fine powder. The Tilemsi phosphate rock (TPR) deposits contain between 23 and 32 % of P₂O₅ and its solubility in neutral ammoniumcitrate is 4.2 %. The chemical composition is (in mg/g): P, 150; Ca, 329; Al, 20; F, 29 (BABANA & ANTOUN 2005).

Procedure

The trial was installed at May, 7th 2007. The experimental field was prepared with a disc harrow and was manually planed. Small dikes were heaped up around every parcel to prevent a transgressing of superficial soil material from one parcel to another in the case of heavy rainfall.

The trial materials were applied in the order TPR, farmyard manure, urine. The application of the substances was done on the prospective seed rows. Four seed rows per parcel were installed, each with 80 cm distance to the other. In treatments where urine was applied, 25 l per parcel were applied. This corresponds to an amount of 17361 l/ha which, in turn, corresponds to an amount of 60.8 kg N/ha, assuming a content of 3.5g N/l in the urine. In treatments where an incorporation of the urine was arranged, 15 cm deep furrows were dug,

where into the urine (and the combined materials, respectively) was applied. Afterwards the furrows were closed immediately.

432g of TPR was applied per parcel. This corresponds to an amount of 300kg TPR/ha. 3.5 kg of this amount were directly plant available (P content of 29% corresponds to 87 kg P/ha, 4.2% of this amount directly plant available).

12 kg of farmyard manure was applied per parcel, that corresponds to an amount of 8.33 t/ha.

Soil samples were taken three times: before application of the experimental materials, 15 days after application and 30 days after application. One sample was taken per seed row, from 0 – 30 cm depth. The four samples per parcel were put together to form a mixed sample. The soil samples were analysed in the laboratory of the institute for rural economy in Bamako. PH-value, the organic matter content (C_{org}) and the nitrogen content (N_{tot} according to Kjeldahl) were measured.

Cotton was planted begin of July and harvested end October (after the internship has already ended).

Statistical analysis

Analyses of the yield results were performed in form of a variance-analysis as described by SCHUSTER & LOCHOW (1979). SCHUSTER & LOCHOW suppose to test, by using a F-Test, which of the tested factors and combinations of factors show a significant impact on the yield results. A listing of least significant differences is compiled in order to make significant differences between several means easy to identify. Afterwards, the average of different treatments is investigated. Therefore, the average is build over all combinations that feature a certain treatment (e.g. urine superficial: average over U_s , U_s+OM , U_s+P and U_s+P+OM). The difference between two means has to be bigger than the related least significant difference to qualify as significant (probability of error 5%).

For tests of significance of the chronologically related measurements of soil parameter, a t-test for repeated measures was performed by using SPSS.

4. Results

Yield

First of all the results of yield should be presented, as they inherent most relevance in this trial.

Yield of cotton was measured; the results are shown in Table 2.

Tab.2 Yield (kg/ha) of cotton (capsule and fibre) for every treatment, average over the four repetitions

Treatment	Yield (kg/ha)
k.A.	1189
Uo	1647
Ut	1845
P	1326
OS	1644
Uo + P	1860
Uo + OS	1813
OS + P	1896
Uo + OS + P	1844
Ut + P	2295
Ut + OS	2169
Ut + OS + P	1925

Results are normal distributed (Kolmogorov-Smirnov-test).

The results of the test of significance for the impact of each factor as well as the calculated least significant differences for comparison of means according to SCHUSTER & LOCHOW (1979) are shown in Table 3.

The F-test shows a significant impact of the urine applications on the yield. Interactions of combinations cannot be proven as significant.

Tab.3 Results of the test of significance for the impact of each factor on the yield and calculated least significant differences (kg/ha) for comparison of means

	F-Test	Least significant difference (kg/ha)
Impact Urine	10.20*	243
Impact OM	3.65	198
Impact P	2.01	198
Interaction Urine/OM	2.79	343
Interaction Urine/P	0.08	343
Interaction OM/P	1.65	280
Interaction Urine/OM/P	1.44	485

* Significant impact (P=5%)

The average values of yield of treatments with different urine application are shown in table 4.

Tab. 4 Average values of yield of treatments with different urine application

	Without urine	Urine superficial	Urine incorporated
Mean	1514	1791	2059

The difference between treatments without urine application and those with a superficial application is 277 kg/ha. The difference is higher than the related least significant difference ($277 > 243$), thus significant. Between treatments with incorporated urine and treatments with a superficial application the difference is significant as well ($268 > 243$). Hence, the incorporation of urine implicates not just a statistically proven higher yield compared to no application, but also compared to a superficial application.

Treatments where the application of urine was combined with rockphosphate showed a slightly higher yield, but not on a significant level. The same is the case for the combination of urine and organic matter (farmyard manure).

Soil samples

The results of analyses of N_{tot} are shown first (Fig.1).

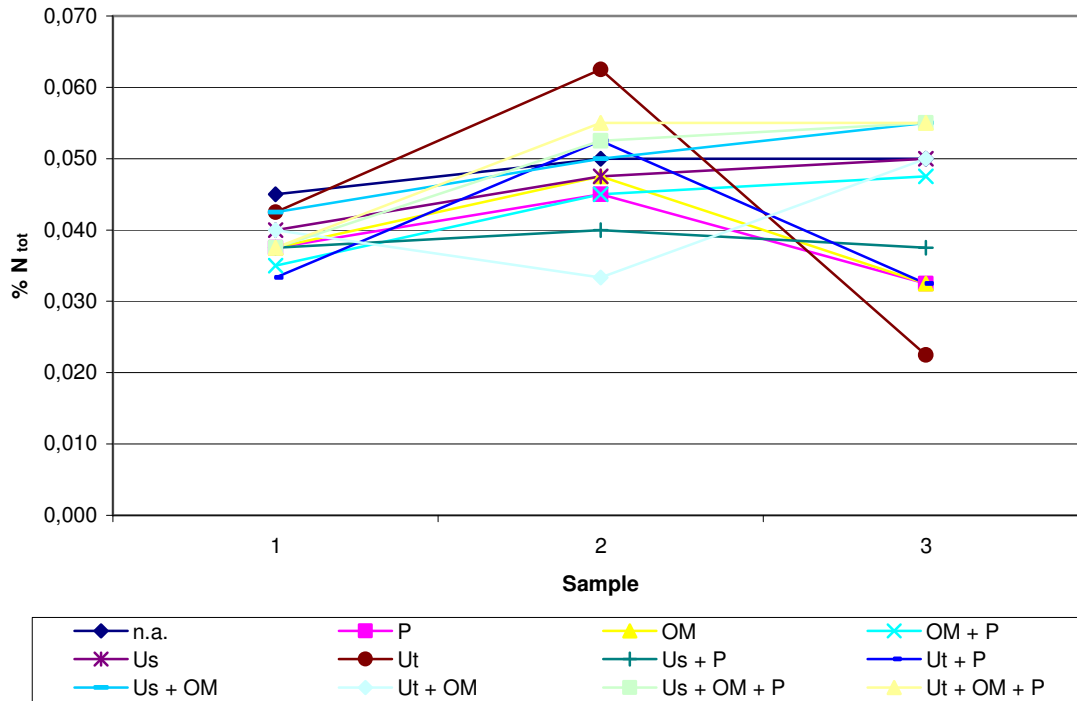


Fig.1 Development of N-Content (N_{tot} %) in the soil in each treatment (1=before application of materials, 2= 15 days after application, 3= 30 days after application)

As results vary strongly, no comparison between treatments was performed. In the following, the mean of treatments with an application of urine is shown (Fig. 2).

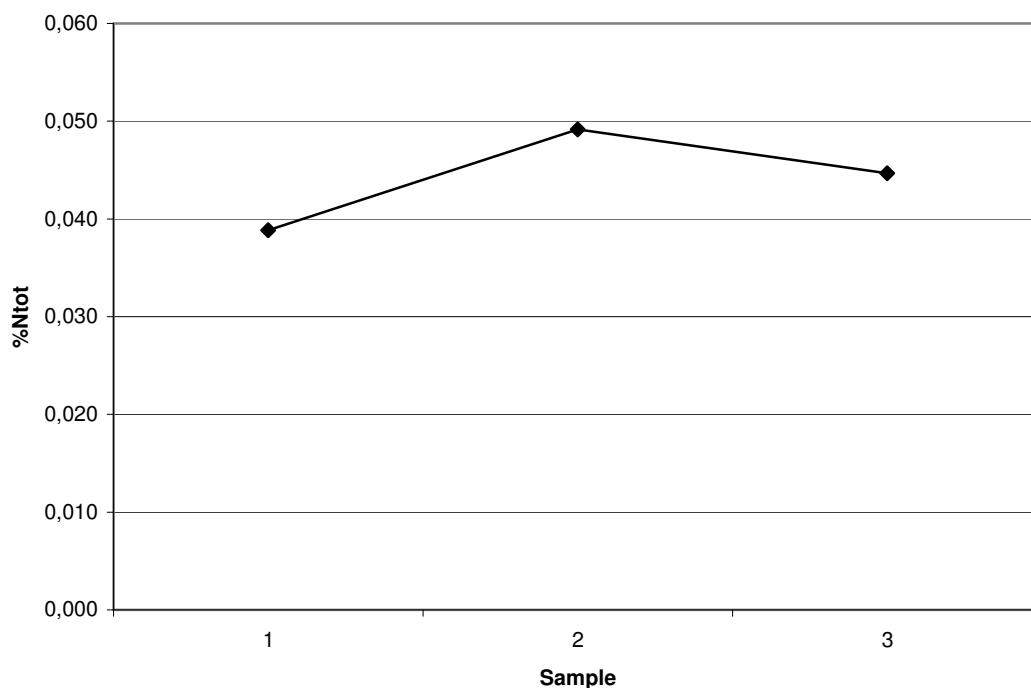


Fig.2 Development of N-Content (N_{tot} %) in the soil, average over all treatments with application of urine (1=before application of materials, 2= 15 days after application, 3= 30 days after application)

A comparison between means of all treatments with application of urine is shown in Table 5.

Tab.5 Means of N-Content in the soil (N_{tot} %) of all treatments with application of urine (1=before application of materials, 2= 15 days after application, 3= 30 days after application), different letters indicate significant difference (P=5 %)

Sample	N-Content in the soil (N _{tot} %)
1	0.0389 ^a
2	0.0492 ^b
3	0.0447 ^b

The results of the measurements of the soil pH-value are shown in the following figure.

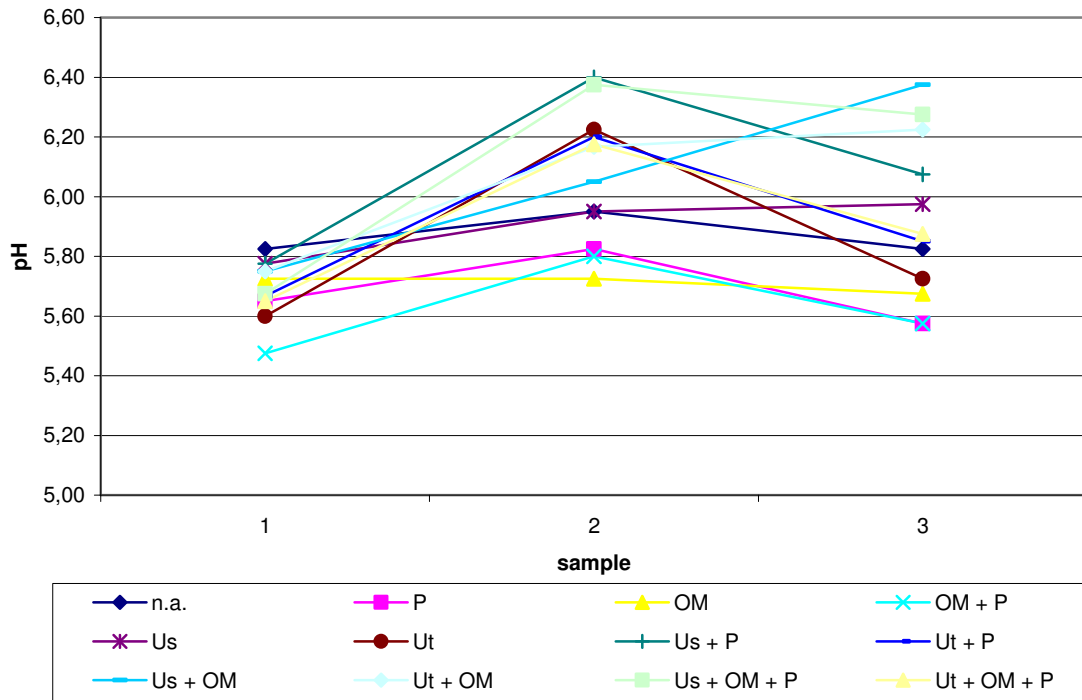


Fig.3 Development of pH in the soil in each treatment (1=before application of materials, 2= 15 days after application, 3= 30 days after application)

The following figures permit a comparison of the mean pH-value between all treatments with urine application and all treatments without urine application.

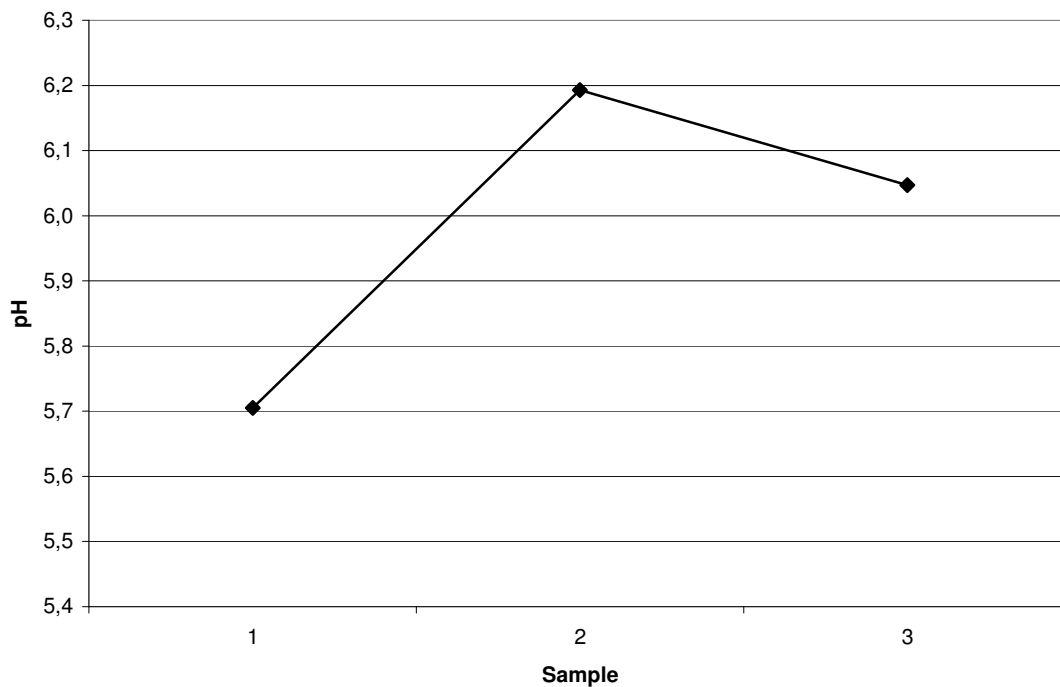


Fig.4 Development of pH in the soil, average over all treatments with application of urine (1=before application of materials, 2= 15 days after application, 3= 30 days after application)

Comparable to the measurements of nitrogen content in the soil, the pH-value of the first sample is significantly different from the second and third sample, while there is no significant difference between the second and third sample.

In treatments without urine application the changes in the pH-value are much smaller (Fig.4) and do not qualify as significant.

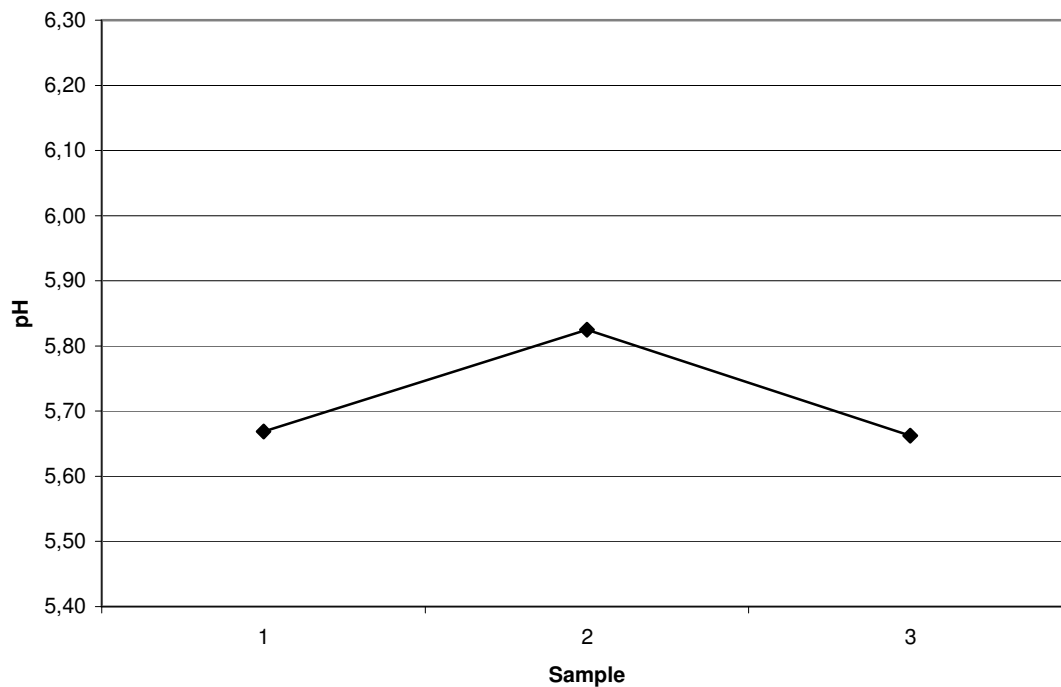


Fig.5 Development of pH in the soil, average over all treatments without application of urine (1=before application of materials, 2= 15 days after application, 3= 30 days after application)

Measurements of the organic soil content vary widely (as shown in table 6), and no reasonable interpretation is possible. Therefore, no further analyses were performed.

Tab. 6 Results of measurements of the organic matter content in the soil, mean and coefficient of variation, all treatments

	1.sample	2. sample	3. sample	Difference 1. - 2.sample	Difference 2. - 3.sample
Mean (%C _{org})	0.23	0.42	0.21	+ 0.19	- 0.21
Coefficient of variation	88.3%	49.9%	42.0%	165.5%	108.1%

5. Discussion

The yield results document the fertilizing effect of urine. It can be surely stated that an application of urine improves the yield, even when applied already ahead of the growing season. Nevertheless, no clear statement about the extent of nitrogen losses related to the early application can be derived from the experimental data.

The fertilising effect occurs even when the urine is not incorporated into the soil. But the yield is significantly higher when the urine is incorporated into the soil after application. After storage, the form of nitrogen in the urine is ammoniac, in a chemical equilibrium with ammonium. Hence, comparable to slurry, high volatilisation of ammoniac is expected immediately after the application of urine. These losses can be reduced through incorporation, thus the yield improving effect of the urine can be fully utilised (RICHERT STINTZIG et al. 2001).

With regard to the hypothesis of the field trial, no conclusions about a temporal immobilisation of nitrogen of the urine can be made. It has to be questioned if losses of nitrogen can be expected during the dry season. SOMDA et al. (1997) have investigated changes in the concentration of mineral nitrogen in the soil after an application of sheep and cattle urine during the dry season. The concentration of N in the soil rose due to the application, decreased only slightly during the dry season, but fell significantly after the begin of the rainy season. SHANDEH et al. (2004) describe even a rise of the mineral N-concentration (without application of any fertiliser) for soils in Mali during the dry season. With onset of the rainy season they observed a sharp increase of mineralisation and mineral nitrogen concentration, followed by a decrease to the same extend in the days afterwards. AUGUSTINE & McNAUGHTON (2004) stress the importance of water for microbiological activity and assume reduced immobilisation and an increasing concentration of mineral N with increasing dryness. Additionally, they describe a very limited rate of nitrification during the dry season. Hence, even with short rainfalls no losses of nitrogen due to leaching have to be expected.

Regarding the activity of phosphor solubilising microorganisms, according to BABANA & ANTOUN (2005) it cannot be expected that they are present in sufficient quantities in all soils of Mali. Therefore, they recommend an incubation of the seeds with appropriate microorganisms which have to be isolated before. Due to their probable limited quantity in the soil and their limited activity caused by the lack of water, it is not likely that phosphor

solubilising microorganisms contribute to an immobilisation of nitrogen of urine during the dry season.

According to what can be concluded from previous experiments, neither high losses of nitrogen, nor a biological immobilisation has to be expected during the dry season. These processes are more important during the rainy season and should therefore be investigated at that point of time.

The assumption pointed out above is supported by the chronological sequence of the measured values of nitrogen content. Application of urine increases the content of nitrogen in the soil. Losses of nitrogen due to volatilisation appear immediately after the application and not later. As there have been only 6 mm of rain between the first second and the third measurement, leaching as well can be excluded. Thus, no further losses of nitrogen were to be expected (between the second and the third measurement). This is confirmed by the experimental data (no significant difference between second and third measurement).

Measurements of the pH-value in the soil show a raise in all treatments with application of urine. This can be attributed to the high pH value of the urine (> 9,0) (see RICHTER 1997, SOMDA et al. 1997, SUNDIN 1999). SOMDA et al. (1997) have applied sheep urine punctually and documented an increase of the pH value from 5 to 8 at the points where the urine was applied. 150 days after the application the value dropped back to 7. In areas that were horizontally and vertically in some cm distance to the point of application, the pH-value raised less and dropped back to the base level within 90 days. The decline in pH-value is due to nitrification which starts with the rainy season, and to the transport of ions. The increase of the pH-value after application of urine is therefore spatially and temporally limited.

The high variations in the measurements of the content of organic matter in the soil can have several reasons. Beside mistakes during analysis in the laboratory also mistakes during sampling could have occurred. On some parcels activity of termites was observed, which also could have influenced the results.

It must be stated that measurements different from those that were performed in this field trial would have been more appropriate in order to answer the questions formulated as subject of this field trial. An examination of soil samples for their content of inorganic N (ammonium and nitrate) as they were performed in some of the quoted publications (SOMDA et al. 1997, SHAHANDEH et al. 2004) is more suitable to trace what happens in the soil with the

nitrogen applied with the urine. Even more exact measurements can be made by using ¹⁵N-marked nitrogen; but this kind of investigation would have been too complex for this trial. As evidence for microbial activity and related temporal immobilisation of Nitrogen, soil respiration or enzyme activity could have been measured (see FORMOWITZ et al. 2007). At least, soil sampling could have been continued over a longer period, as it was actually done in the experiment, but results were not available until the completion of this report.

A good indicator for availability and fertilising effect of applied nitrogen is the N-uptake of the plants under investigation. An examination of N-content in the cotton plants was planned, but the results were as well missing. Furthermore, it would have been useful to establish a treatment in the trial, where the urine would have been applied just before sowing. The available results are not sufficient to assess if an application during the dry season has clear disadvantages compared to an application before sowing.

The points just mentioned should be considered in further experiments in order to answer the questions formulated in this experiment more satisfactorily.

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Appendix

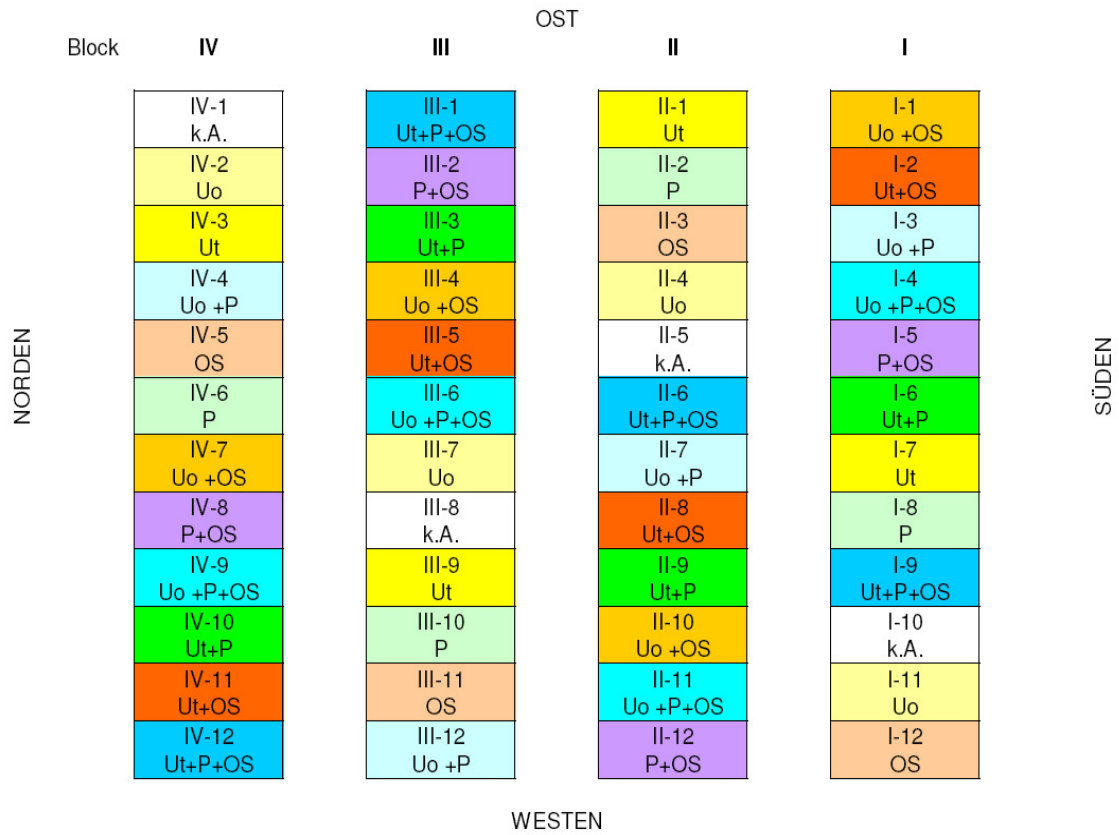


Fig. A1 Experimental design