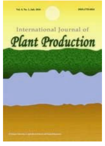

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Influence of human urine combined with farm yard manure and chemical fertilizers on french bean and maize cropping sequence in lateritic soils of Karnataka, India

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Abstract

The introduction of ecological sanitation (ECOSAN) toilets in villages near Bangalore has created opportunities for safer sanitation and recycling of human excreta, as fertilizers, in rural and peri-urban areas. Field experiments were conducted at the University farm on French beans and Maize as the test crops in succession for 2 consecutive years in the same field. Different treatment combinations tried include human urine, with and without gypsum, Farm yard manure (FYM), chemical fertilizers and control. The fertilizer value of human urine were assessed and supplied to the crops based on the nutrient content. The results revealed that yield of two crops were significantly highest in treatment receiving human urine + FYM followed by human urine alone. Generally the results showed that human urine performed well than the commercially available chemical fertilizers (urea) applied as a source of N for crops and does not pose any significant hygienic threats and leave any significant flavor in food products.

Keywords: Cattle urine; Farmyard manure; Fertilizers; Human urine; French bean and Maize.

Running Title: Anthropogenic wastes as nutrient source for crop production.

Introduction

The global population is expected to grow by about 35% by 2050, increasing the demands on agricultural production and use of chemical fertilizers. Scientists in the past have reported indiscriminate mining of N, P and K from soil reserves in all the agro-climatic zones across India (Yadav et al., 2001; Surendran and Murugappan, 2007; 2010; Surendran et al., 2016b) resulting in depletion of nutrients and the impact is clearly visualized on the agricultural production. The compound growth rate in yield of major crops in India is either declining or negative over the period of 1980-81 to 2011-12 (MoA, 2013).

Although the use of chemical fertilizer is the fastest way of counteracting the pace of nutrient depletion, its increasing cost and limited availability deter the farmers from using these inputs in balanced proportions thereby paving way for the problems of environmental pollution. Chemical fertilizers of many kinds are widely used, but the materials to create them are becoming increasingly more difficult to obtain. The nitrogen, phosphorus and potassium that make up the majority of these fertilizers come from finite resource pools. The majority of nitrogen is made from natural gas and is subject to price fluctuations and availability of methane. The global potassium mines should last several centuries, but the global phosphorus mines are set to run out in less than a century (Van Vuuren et al., 2010). The cost of making and buying fertilizer is further exacerbated by fluctuations in oil price and the fertilizer costs increased to nearly triple and food transportation costs doubled (FAO, 2010).

Scientists are currently interested in developing alternative technology to minimize the dependence on chemical fertilizers and encourage the other viable options on a large scale by the farming communities (Surendran and Vani, 2013; Surendran et al., 2016a). A new paradigm is to focus on the resources that can be recovered from wastewater rather than the constituents that must be removed. Current human waste collection systems do much to minimize human contact with the pathogens in excrement, but little to ensure that those nutrients will be returned to natural systems in a way that benefits food production and soils. Today human excreta are almost universally looked upon as a hazardous waste to be disposed off. However, the nutrients in urine and faeces derive from ingested food and, if recycled, might be important as fertilizer in future agriculture. On one hand, around 2.4 billion people do not have sanitation facility and about 2 million people die every year due to diarrheal diseases, most of them are children <5 years of age (WHO, 2010). On the other hand, fertilizer demand is increasing by increasing food demand to feed the increasing population. Since fertilizer is a very important means to increase the food and fertilizer is becoming expensive, this problem can be partly solved by using human urine as a fertilizer.

Human urine is a valuable, yet underestimated and underutilized, resource for plant fertilization that has been used in agriculture since ancient times (Goldstein, 2012). Until green revolution, the demand for additional fertilizer sources was low since agricultural land was generally fertile and farmers practiced shifting cultivation. Moreover, the handling of human waste is often surrounded by cultural norms and taboos, which restrict its use in agriculture (Dellström Rosenquist, 2005). About 80% of the global ammonium nitrate production is by fixation of atmospheric nitrogen using natural gas as a source of both hydrogen and energy (Brentrup and Pallière, 2008). The global warming impact from nitrogen fertilizer production is mainly due to the large emissions of carbon dioxide (CO_2) when using natural gas and of nitrous oxide (N_2O) from the nitric acid production, a step within the nitrate production process (Brentrup and Pallière, 2008). The use of phosphate rock for the production of chemical fertilizers is also a concern, as the life time of economic reserves of phosphate rock is finite and is estimated to be exceeded in the next 30-37 years (Cordell and White, 2011; USGS, 2013). Hence, recycling the nutrients in human excreta to arable land as fertilizer can reduce the use of energy and non-renewable resources for production of chemical fertilizers.

The use of urine as a source of nutrients / (fertilizer) has been tested, gaining popularity and accepted partially in Finland, South Africa, Israel, Sweden and China (Rodhe et al., 2004; Heinonen-Tanski et al., 2007; Pradhan et al., 2007; Pradhan et al., 2009; Winker et al., 2010). Human urine contains all the essential nutrients required by the plants. The fertilizer value of pure urine is similar to NPK fertilizers. Still these non-technical aspects are often neglected both by scientists and by developers of new technologies. One of the best options is to utilize human urine as liquid fertilizer which has appreciable quantities of nutrient elements required by plants but is being wasted. Human excreta and urine, which contains appreciable quantity of nitrogen (N), phosphorus (P) and potassium (K). Urine has a fertilizer value of N/P/K 18:2:5 (Linden, 1997) and for urine mixed with flush water, the ratio can be N/P/K/S 15:1:3:1 (Palmquist, 2007). The nitrogen in urine mainly consists of ammonium and has 85-100% of the plant availability of the nitrogen in chemical fertilizers (Jönsson et al., 2004). The phosphorus in urine is mainly in the form of phosphate ions and is as available to plants as soluble phosphorus fertilisers.

Each individual produces 1-1.5 L of urine per day, the chemical composition of which depends on his/her feeding habits, the amount of drinking water consumed, physical activities, body size and environmental factors. In general, pure human urine contains very few enteric microorganisms (Heinonen-Tanski et al., 2007). The nutrient content present in human urine may mean it can be a good fertilizer for plants. This may be increasingly important in the future, with population growth and the corresponding increase in the demand for food and demand to save water and energy.

In recent years, a number of source-separation techniques, especially for urine separation, have been investigated. One review by Maurer et al. (2006) concluded that there are many urine treatment processes available both for hygienisation and nutrient-recovery, e.g. struvite precipitation and ammonia stripping. For separating urine, special toilets have been developed with a front bowl collecting the urine and a rear bowl collecting the faeces and toilet paper. The urine is piped to a storage tank for further treatment.

The use of human urine in agriculture is not possible with the present system of sewage disposal mechanisms. The toilets and urinals in urban centers will have to be redesigned to collect the faecal matter and urine separately. In this direction an eco-friendly design of toilet called 'ECOSAN' (Urine diverting toilets) is being currently used in urban and peri urban areas of India needs to be popularized which help in source separation of human urine and faecal matter in a hygienic way. The standard procedure and protocol of using human urine in crop production is not well documented in India. By keeping all these points, the present study was carried out with the main objective to assess the nutritive value of human urine with and without gypsum on French bean and maize cropping sequence.

Materials and Methods

Experimental Site and Soil Characteristics

Field experiments were conducted for two years at the main research station of University of Agricultural Sciences, GKVK, Bangalore which is located in the eastern dry zone of Karnataka and the site characteristics were presented in Table 1a. The soils of the experimental fields were analyzed for their physico-chemical properties are presented in Table 1b along with the site characteristics.

Table 1. Characteristics of the study area.

1a.Site Characteristics	
Experimental site	Researh farm of University of Agricultural Sciences, GKVK, Bangalore
Latitude/Longitude	12° 58’ North latitude, 77° 35’ East longitude
Elevation (above mean sea level) (m)	930
Mean annual maximum Temperature (^{o}C)	28.0
Mean annual minimum Temperature (^{o}C)	20.8
Mean annual Rainfall (mm)	593.3
Major soils	Lateritic soils
Major crops grown	maize (*Zea mays*), sorghum (*Sorghum bicolor*), variety of pulses and vegetables
Preceding crop in the experimental plot	Maize (*Zea mays)*
1 b. Soil Characteristics	
Soil series	Vijayapura
USDA Taxonomical class	*Oxichaplustalf*
Texture	Sandy clay loam
pH	5.97
EC (dSm^{-1})	0.14
Organic carbon (%)	1.45
Available N (kg ha^{-1})	347.8
Olsen- P (kg ha^{-1})	41.62
Exchangeable K (kg ha^{-1})	283.8

Nutrient composition of urine and FYM

The nutrient composition of urine of differs from country to country and is basically based on diet. The composition of cow urine and FYM may also vary. Hence these were analyzed. The nutrient composition of human urine and cattle urine used for experiment are given in Figure 1.

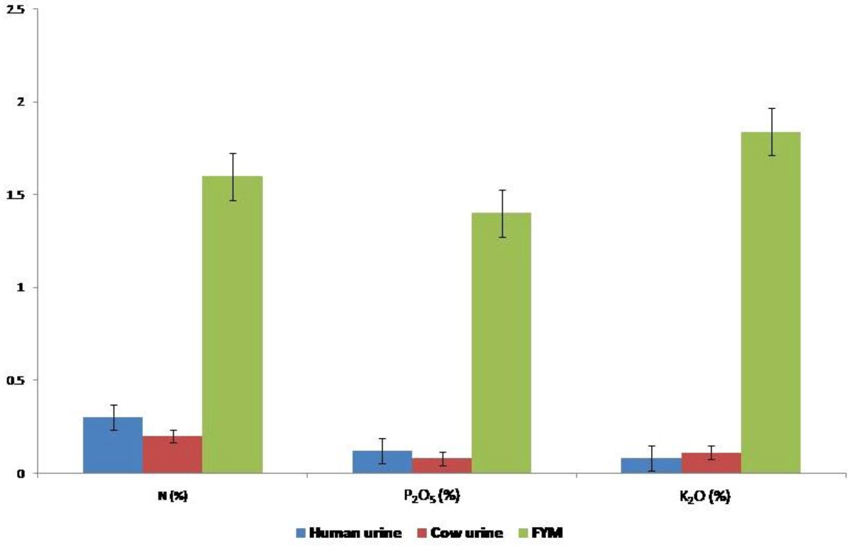


Figure 1. Initial nutrient content of Human urine, cow urine and FYM used for experiment.

Crop details

A French bean-maize cropping system has been practiced in the field for the past 2 years.

The experiment was laid out with a set of ten different treatments in randomized block design with three replications (Table 2). The recommended dose of fertilizers (RDF) for test variety of french beans and maize is 63:100:75 and 150: 75:40 kg of NPK ha^{-1}, respectively as per the Karnataka package of practice hand book. The required quantity of N, P and K were applied in the form of urea, single superphosphate and muriate of potash, cow urine and human urine as per the treatments. In treatments, N was given based on the nitrogen content in human urine, cow urine and FYM (Tables 3 and 4). Balance of P and K were supplied through chemical fertilizers, Phosphorus through single super phosphate and Potassium through muriate of potash. The urine was applied in rose can for uniform soil application. Basal application of urine was done before sowing the seeds to supply 40% of nitrogen and the balance 60% N was supplied through human urine/cattle urine (two split dose was) given before fifty per cent of flowering. The balanced recommended dose of P&K was applied to the plots at the time of sowing. Gypsum was used as an amendment. The gypsum requirement was calculated based on the solubility of gypsum, field capacity of the soil and quantity of human urine. To attain hundred per cent saturation, two grams of gypsum per litre of human urine was used. The total quantity of gypsum per plot was calculated based on the amount of human urine to be added for each plot. All the cultural and management practices were followed uniformly to all plots as per the package of practices in both the crops. The growth and yield parameters were recorded by adopting standard procedures.

Table 2. Treatment structure.

Sl.No	Treatment details
T_1	RDF* through Human urine (HU) @ 40% basal + 60 % in 3 splits without gypsum
T_2	RDF through Human urine (HU) @ 40% basal + 60 % in 3 splits with gypsum
T_3	RDF through Cow urine (CU) @ 40% basal + 60 % in 3 splits without gypsum
T_4	RDF through Cow urine (CU) @ 40% basal + 60 % in 3 splits with gypsum
T_5	40% of RDF through FYM basal+ 60% through human urine (HU)
T_6	40% of RDF through Chemical fertilizers basal + 60% through human urine (HU)
T_7	40% of RDF through FYM basal+ 60% through Cow urine (CU)
T_8	40% of RDF through Chemical fertilizers basal + 60% through Cow urine (CU)
T_9	Absolute control (No nutrients)
T_{10}	100% RDF through Chemical fertilizers

* RDF – Recommended Dose of Fertilizers.

Table 3. Quantity of human urine(HU), cow urine(CU), FYM and chemical fertilizers applied to grow french bean crop.

Treatments	Qty. of HU/CU required (l/ha)	Qty. of Gypsum (kg/ha)	Basal application					Top dressing
			HU/CU (l /plot)	FYM (kg /plot)	Urea (g /plot)	SSP (g /plot)	MOP (g /plot)	HU/CU (l/plot/split)
T_1	33333	-	7.26	-	-	404	84	3.63
T_2	33333	42 (36.29 g/plot)	7.26	-	-	404	84	3.63
T_3	50000	-	10.89	-	-	404	58	5.44
T_4	50000	63 (54.43 g/plot)	10.89	-	-	404	58	5.44
T_5	20000	-	-	1.35	-	340	52	3.63
T_6	20000	-	-	-	47	458	93	3.63
T_7	30000	-	-	1.35	-	340	37	5.44
T_8	30000	-	-	-	47	458	78	5.44
T_9	-	-	-	-	-	-	-	-
T_{10}	63:100:75 NPK (kg/ha)							

Table 4. Quantity of human urine, cow urine, FYM and chemical fertilizers applied to grow Maize.

Treatments	HU/CU (l/ha)	Basal application			Basal FYM	Basal application				
		FYM (kg/ha)	HU/CU (l/ha)	HU (l/ha/ split)		HU/CU (l/plot)	FYM (kg/plot)	Urea (g/plot)	SSP (g/plot)	MOP (g/plot)
T_1	50000	0	20000	10000	0	18	0	-	81	0
T_2	50000	0	20000	10000	0	18	0	-	81	0
T_3	75000	0	30000	15000	0	27	0	-	81	-61
T_4	75000	0	30000	15000	3.21	27	0	-	81	-61
T_5	30000	3726.71	0	10000	0	0	3.219	-	-113	-76
T_6	30000	0	0	10000	3.21	0	0	78	211	23
T_7	30000	3726.71	0	10000	0	0	3.219	0	-49	-89
T_8	45000	0	0	15000	0	0	0	78	211	-14
T_9	0	0	0	0	0	0	0	-	-	-
T_{10}							8.64	281	405	64.8

Soil and Plant analysis

In order to assess the influence of urine on the agronomic performance, soil fertility and nutrient balance, representative soil samples were taken from each treatment plot. Samples were taken from the cultivated soil layer (upper 15 cm), using a single auger and combining 12 samples evenly distributed over the field to one composite sample. The samples were air dried, crushed and gravel and other particles of more than 2 mm were removed with a sieve. The samples were analysed in the soil laboratory of Department of Soil Science and Agricultural Chemistry, University of Agricultural Sciences, for the parameters listed in Table 5. Nutrient analysis was limited to N, P and

K only. Similarly stage wise plant samples were collected and kept for nutrient uptake pattern analysis. N, P and K content in plant parts were analyzed using standard analytical procedures and expressed as percentage on dry weight basis and computed to kg ha^{-1}.

Table 5. Soil and Plant parameters and analytical methods.

Parameter	Method	Reference
Soil parameters		
Texture (sand, silt, clay)	Hydrometer	Day (1965)
pH	1: 2.5 soil water	Jackson (1973)
Organic Carbon	Wet Digestion	Walkley and Black, (1934)
Nitrogen	Alkaline Permanganate method	Subbiah and Asija (1956)
Phosphorus	Bray method	Bray and Kurtz (1945)
Potassium	Ammonium acetate extractable K	Stanford and English (1949)

Statistical analysis

Statistical analyses of the data were carried out according to randomized block design. The experimental data were pooled and the mean data of two years were subjected to statistical scrutiny as per methods suggested by Gomez and Gomez (1984). All the parameters were subjected to analysis of variance (ANOVA) and the data were analyzed for its statistical significance. Fisher's Least Significant Difference (LSD) was used to test the significant differences between the means, at probability level $P \leq 0.05$ using the ANOVA (Analysis of Variance). The non-significant treatment differences were denoted as NS.

Results and Discussion

Soil properties

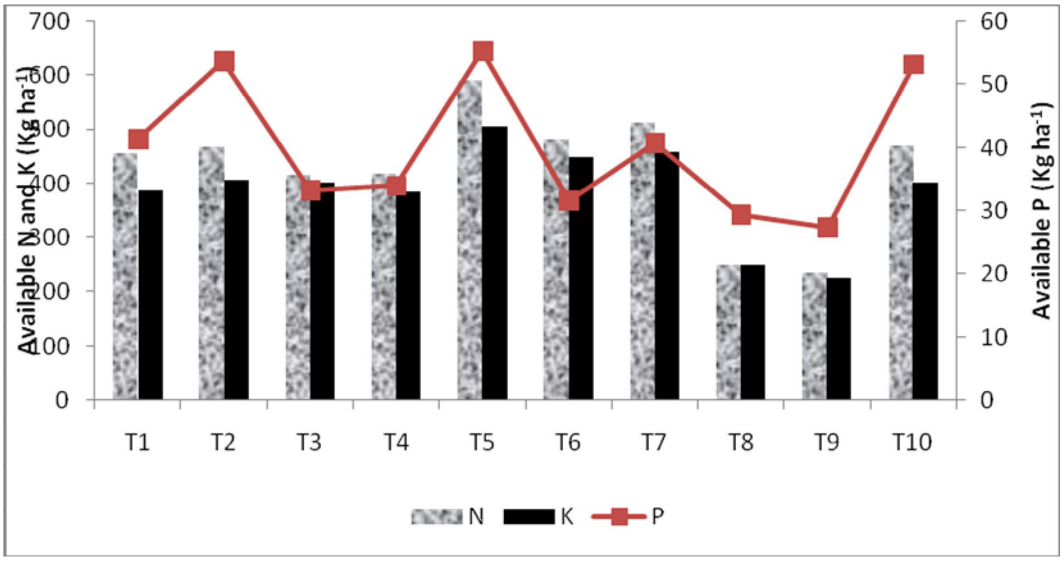
The pH and EC of the soil were significantly affected by different treatments tried. In the first crop of french bean, higher pH (6.65) was noticed in treatment (T_7). During second year after the harvest of maize also the same treatment recorded higher pH (6.69). The higher EC value was noticed in human urine alone treatment T_1 (0.41 dSm^{-1}) when compared to control. This is attributed due to the presence of higher quantity of salts in human urine which in turn depends upon diet (Table 6). During second year also, the soil properties were found to be congenial for plant growth. The EC of the soil was significantly affected by different treatments. Application of human urine has increased the EC of soil slightly. The higher EC value (0.43 dSm^{-1}) was noticed in human urine alone treatment (T_1) when compared to control. Similar results of increase in EC of soil with application of human urine were reported by Mnkeni Pearson, (2008). However, all these values are below the permissible limits and hence it might have turned beneficial for plant growth. This is attributed to the presence of higher quantity of salts in human urine which might have contributed for the increase in values (Table 6). The organic carbon content was found to increase significantly among the treatments. The treatments which received FYM plus human urine were found to register higher values of organic carbon at harvest stage of crop compared to chemical fertilizers and cow urine treatments. The highest mean organic carbon content (1.48 per cent) was registered in treatment T_5 which received 40% RDF. N through FYM basal+ 60% through human urine. Similar trend of results were observed after the harvest of maize crop also.

Table 6. Effect of human urine, cattle urine FYM+HU on pH and EC of soil at harvest stage of crop in two years.

Treatments	pH (1:2.5)		EC (dSm^{-1})		Organic carbon (%)	
	1^{st} crop	II_{nd} crop	1^{st} crop	II_{nd} crop	1^{st} crop	II_{nd} crop
T_1	6.11	5.89	0.41	0.43	1.19	1.18
T_2	5.73	6.18	0.40	0.39	1.22	1.20
T_3	5.65	5.72	0.16	0.15	1.08	1.08
T_4	6.12	6.12	0.18	0.17	1.16	1.11
T_5	6.15	6.25	0.16	0.13	1.58	1.48
T_6	6.15	6.15	0.13	0.11	1.13	1.12
T_7	6.65	6.69	0.13	0.13	1.20	1.09
T_8	6.35	6.42	0.14	0.14	1.06	1.06
T_9	6.03	6.05	0.14	0.09	1.07	1.02
T_{10}	6.12	6.14	0.10	0.12	1.32	1.32
SEm±	0.16	0.14	0.12	0.10	0.12	0.12
CD (P=0.05)	0.49	0.47	0.35	0.35	0.35	0.36

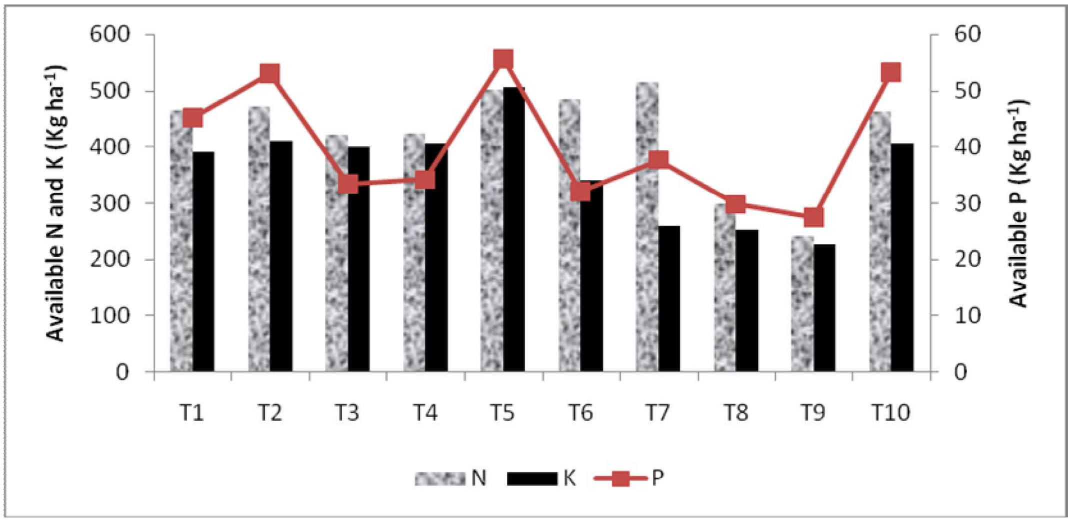
1^{st} crop - French beans
II_{nd} crop - Maize

The higher mean of soil available nitrogen (591.72 and 502.55 kg ha^{-1}), phosphorus (55.31 and 55.72 kg ha^{-1}) and potassium content (504.98 and 506.29 kg ha^{-1}) of soil was observed in treatment T_5 which received 40% RDF. N through FYM basal+ 60% through human urine (Figures 2 and 3). The possible reasons might be good release of nutrients from the sources and their positive interaction. Human urine is a soluble liquid fertilizer, which mean that nitrogen is more rapidly available and effective even in dry season (Jonsson et al., 2004). The post-harvest soil analysis revealed that plots receiving direct urine application had almost three times higher phosphorus content than the control plots. Nitrogen and potassium content was also higher, which might suggest a residual build-up of these nutrients in the soil following urine application (Semalulu, 2012).



SEm±	17.36	2.47	14.1
CD (P=0.05)	52.04	7.41	42.31

Figure 2. Effect of human urine and other treatments on soil available nutrients for French beans crop.



SEm±	14.8	0.57	14.4
CD (P=0.05)	44.55	1.71	43.3

Figure 3. Effect of human urine and other treatments on soil available nutrients for Maize crop.

Crop yields

Higher french bean yield was observed in treatment T_5 (4.87 t ha^{-1}) which received 40% RDF. N through FYM basal+ 60% through human urine when compared to other treatments. The lower value (1.19 t ha^{-1}) was recorded in control (T_9). In the second crop (maize) also, T_5 treatment registered higher yield (6.89 t ha^{-1}) compared to other treatments. The control has recorded the lowest grain yield of 3.89 t ha^{-1}. The treatment T_7 and T_8 were on par but recorded significantly higher grain yield over absolute control (Table 7). Similar trend was observed in stover yield. Similar type of results were observed by Mnkeni Pearson, (2008). Comparison of results (Table 7), in different treatments however, confirms the positive impact of urine fertilizer on crop growth reported in other studies (Andersson et al., 2011; Pradhan et al., 2010; Semalulu et al., 2011). This increase in yield might be due to ready supply of nitrogen and other nutrients which had a positive impact on overall improvement in crop growth, enabling the plant to absorb more nutrients and the plant could synthesis more of photosynthates and resulted in higher yield. Urine could replace the commercial fertilizer and it could be used in soil having excessively high phosphorus and potassium content (Andersson, 2015). In low P and K soils, urine fertilization needs to be supplemented with ash to improve its phosphorus and potassium contents. In the present study the crops fertilized with the commercial mineral fertilizer as control might have severed from a shortage of nitrogen, limiting its ultimate yield. Application of urine guaranteed a better yield by providing more nitrogen in the later phases of crop growth and this is confirmed by the residual nitrogen in soil data. This indicates a lower or slower nutrient availability from the recovered nutrients than from the highly soluble NPK used. The above observations reflect the fact that urine contains all the major nutrients, as well as the micronutrients, which are required in crop production.

Table 7. Effect of human urine, cattle urine FYM+HU on yield of french beans and maize crops.

Treatments	French bean pod yield (t ha-^{1})	Maize grain yield (t ha-^{1})
T_1- Rec. N -Human urine @ 40% basal + 60 % in 3 splits without gypsum	3.82	6.65
T_2- Rec. N -Human urine @ 40% basal + 60 % in 3 splits with gypsum	3.99	6.82
T_3- Rec. N -Cow urine @ 40% basal + 60 % in 3 splits without gypsum	2.46	6.04
T_4- Rec. N -Cow urine @ 40% basal + 60 % in 3 splits with gypsum	2.41	6.55
T_5- 40% Rec. N through FYM basal+ 60% through human urine	4.87	6.89
T_6- 40% Rec. N through CF basal + 60% through human urine	2.33	5.98
T_7- 40% Rec. N through FYM basal+ 60% through cow urine	3.61	4.04
T_8- 40% Rec. N through CF basal + 60% through cow urine	1.75	4.03
T_9- Absolute control	1.19	3.89
T_{10}- RDF	3.86	6.69
SEm±	0.15	1.41
CD (P=0.05)	0.45	4.23

Conclusion

The present study revealed that the human urine can be used as a liquid fertilizer and it can be a supplement to fertilizers. Under French bean and maize cropping sequence combined application of 40% recommended dose of nitrogen through FYM as basal+ 60% through human urine was found to be beneficial in increasing the crop yield and improving soil fertility status as compared to chemical fertilizers. Based on the data, it can be concluded that new fertilizers from urine have a high potential to introduce a new and promising handling of our water and nutrient (re)sources. It has to be kept in mind that these new products have to be adjusted to the available application techniques in agriculture to guarantee a successful usage. The implementation of new fertilizing products always introduces potentially new transmission routes of infectious diseases or organic pollutants. Nevertheless, as long as we are aware of the inherent risks and address them with appropriate measures, usage of the fertilizing products in agriculture should be possible. However, for many of the fertilizing products deriving from new sanitation systems, further research is required to fill still existing gaps of knowledge and gain further information to optimise handling, treatment and usage of these products.

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