Effects of Human Urine and Ecosan Manure on Plant Growth and Soil Properties in Central Nepal

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Abstract

The effects of human urine and ecosan manure on crop productivity and soil chemical properties were studied using a randomized block experimental design in the households' farm at three sites (Angare, Bhot Khoriya, and Deurali) of the Palung Village Development Committee, Nepal. Cauliflower was planted in 2017 and 2018 with five treatments: Control (C), Chemical fertilizer (CF), Urine (U), Ecosan manure + Urine (E+U), and Ecosan manure (E) during rainy season. The biomass of the plant after three weeks of transplant and after harvest was calculated to analyze the role of the treatments in cauliflower productivity. Chemical analysis was conducted to understand nutrient uptake and efficiency in the different treatments. It was observed that cauliflower yield was significantly higher in E+U and E treatments in Bhot Khoriya and Deurali and increased by 51% and 58% in Angare. Higher Potassium (K) uptake by plants from the E treatments was might be due to higher concentration of K in ecosan manure. Apparent recovery efficiency (ARE) of Nitrogen (N) increased from 9% to 115% due to the incorporation of urine and ecosan manure indicating that urine was a better source of N whereas human faeces were the better source of Phosphorus (P). Higher amount of urine applied might lead to overflow of urine contributing to volatilization and leaching. To minimize such effect, the application of a moderate amount of urine in combination with ecosan is recommended to have a significant effect on crop growth.

Keywords: cauliflower, excreta, nutrient uptake, productivity, urine

Introduction

Global food security is recognized as one of the major challenges for sustaining the nine billion people projected to live on earth by 2050. In a sustainable society, the production of food must be based on returning plant nutrients to the soil. The challenge of finding new options to improve soil fertility for sustainable crop production has resulted in the option of recycling waste materials, including human urine and excreta. In a sustainable society the production of food must be based on returning the plant nutrients to the soil (Winblad and Simpson-Hébert 2004: 2). Ecological sanitation (ecosan) which is defined as a water conserving and nutrient recycling system for the use of human urine and excreta in agriculture and is seen as a potential strategy to both enhance soil fertility and to address sanitation challenges (Langergraber and Muellegger 2005: 441). The urine and decomposed excreta collected from ecosan toilet is used as a fertilizer in agriculture.

The majority of the Nepalese population has traditionally practiced open defecation (WaterAid Nepal 2006: 2). Nepal's Sustainable Development Goals (SDGs) target for 2030 in water and sanitation include achieving universal and equitable access to safe and affordable drinking water, sanitation and hygiene for all and end open defecation (National Planning Commission 2017: 35). Since 2011, the toilet coverage in urban areas is 78% against the rural coverage of only 37% with annual growth rate of sanitation increment at 1.9% (SHMP 2011: 4). The trend analysis showed that if the present trend is continued, the toilet coverage will be only 80% against the national target of

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universal coverage in 2017 (SHMP 2011: 4). This somehow added a burden on households to construct a toilet.

Every year, a large amount of chemical fertilizer is imported from India and other countries to fulfil the fertilizer needs of the country. The high price of chemical fertilizer and its low or untimely availability are challenges for farmers. Excreta and greywater can help to improve food production, especially for subsistence farmers who otherwise might not be able to afford artificial fertilizers (WHO 2006). In such cases, the use of human waste (urine and excreta) as a fertilizer should be explored to enhance productivity and to address the problems mentioned above. Human urine is a valuable source of nutrients that has been used since ancient times to enhance the growth of plants, notably leafy vegetables (Jonsson et al. 2004: 17), and is universally available at no cost. Every day, human beings produce urine, which contains some nutrients that are needed for plant growth (Adeoluwa and Cofie 2012: 292–293). Each year, one person produces 500 kg of urine and 50 kg of excreta. The amount of excreted organic matter in faeces in many countries seems to be in the range of 10 kg (Sweden in addition to 8 kg toilet paper) to 20 kg (China). In both countries, excreta contain 10 kg of organic matter per person per year after being dried (Jonsson et al. 2004: 28). These amounts depend on the person's body weight, water intake, and diet characteristics, especially protein content, and on the climate (Heinonen-Tanski and Wijk-Sijbesma 2005: 404). The nutrients in urine are in ionic form, and their plant availability has been found to be comparable with that in chemical fertilizers (Kirchmann and Pettersson 1994: 152–153; Yogeeshappa and Srinivasamurthy 2017: 1599–1600). The fertilizer value of human urine and its use as a crop nutrient source has received greater attention from researchers in recent times. The study was carried out in Nepal by Upreti et al (2004) to find out the appropriate urine dose and time of application. In the study potato was fertilized with N : P : K at the rate of 150 : 100 : 30 kg ha^{-1}. The result suggested that 2–3 splits urine application in addition with phosphorus and potassium fertilizer from other sources are efficient plant nutrients and can have comparable yield as that of chemical fertilizer. However, the agricultural practices are fundamentally influenced by social and cultural dimensions and is influences farmers' attitudes and choices. (Andersson 2015). Human excreta are used frequently as night soils in some areas of the world such as China, Vietnam and Japan for agricultural production (Heinonen-Tanski and Wijk-Sijbesma 2005: 404). Different sources of urine increase soil pH, total N, organic carbon, Available phosphorus (Avai. P) and exchangeable cations of soil as well as maize grain yield (Nwite 2015: 35). The experiment was conducted in the tunnel house in South Africa by Kutu et al. (2010) with seven human faeces N : urine N combinations (1 : 7 to 7 : 1) each supplying 200 kg N ha^{-1}. The study revealed highest dry yield in 1 : 7 human faeces to urine N combination and comparable yield in 1 : 1.2 and sole urine application. The study also revealed that highest N uptake was in sole urine and 1 : 7 human faeces to urine combination and highest P uptake was in 7 : 1 human faeces to urine combination suggesting that application of human faeces and urine, either separately or in combination, results in increased fresh and dry matter yields of spinach. A study conducted in Ghana with combined urine and poultry droppings suggested urine as a potential source of inputs to use for vegetable production and to increase soil fertility (Amoah et al. 2017: 11). Similarly, the study conducted by Guzha et al. (2005: 844) concluded that the use of urine and excreta led to better maize production than that with urine alone in Zimbabwe. Pradhan et al. (2009) conducted an experiment in tomato cultivation in a greenhouse to evaluate the efficacy of mineral fertilizer (NPK 9-6-17.7 g per plant), mixture of urine and wood ash (81 ml + 10.7 g per plant), only urine (81 ml per plant) and control (no fertilization). The result revealed that the urine fertilized tomato plants produced equal amount of tomato as mineral fertilized plants and 4.2 times more fruits than non-fertilized plants. Also, experimental trials in a skyloo humus (soil mixed with faeces and ash) with different urine application rate (water urine ratio of 3 : 1, 5 : 1, 10 : 1) were conducted for maize in Zimbabwe. The result showed 6 to 35 times increase in yields of maize when fed with urine than with that of water only as a result of the addition of urine as a liquid fertilizer (Morgan 2003) suggesting humus as an excellent medium for growing plants. However, studies on the feasibility of combined urine and excreta-based farming systems for vegetable production are limited. In ancient days, farmers in Nepal practicing vegetable production with urine and excreta would empty pit latrines onto the farmland. Gradually, the farmers shifted towards constructing toilets with septic tanks and started disposing of toilet waste into nearby rivers or drainage rather than using it on their farm. Hence, the possibility of the systematic use of urine and ecosan manure from ecosan toilets should be explored to enhance the productivity of rural agriculture and to maintain the cleanliness of the rural environment. Hence, this research was conducted in Central Nepal with the objective of evaluating the effects of human urine and ecosan manure on cauliflower production, nutrient uptake and soil chemical characteristics.

1. Materials and methods

1.1. Study area

This research was conducted in the Palung Village Development Committee (VDC), Makwanpur district in central Nepal. The district is located south of Kathmandu, the capital city of Nepal (Figure 1). The district has a subtropical to alpine climate. The maximum temperature rises up to 34°C, and the minimum temperature falls as low as −1.6°C (DoLIDAR 2012: 13). The rainfall is mainly due to the southeastern monsoon. The mean annual precipitation varies from 1,971 mm to 2,331 mm per year, approximately 80% of which falls between June and September (DoLIDAR 2012: 13). The major occupation in the district is agriculture. The total population of the district is 420,477 (CBS 2012). Approximately 82.7% of the population mostly depends on agriculture (DoLIDAR 2012: 16). The major agricultural product in this district is cereal crops. Paddy production, fruits and vegetables are the other main agricultural products in this district for domestic use and for export to other districts, particularly to Kathmandu.

1.2. Experimental site and preparation of urine and excreta

Five ecosan toilets were constructed for five households in the Palung VDC in 2016 as a demonstration project. Among them, at one household farm in each of the three villages (Angare, Bhot Khoriya and Deurali), a field experiment was carried out from June to September 2017 and July to October 2018 during the rainy seasons. The field experiment was conducted for the three households with differences in household economy and altitude. Angare, Bhot Khoriya and Deurali are located at 1,822 m, 1,981 m and 2,125 m above sea level, respectively. The average soil temperatures at depths of 0–5 cm during the cropping season (9 July–3 September) in 2018 at Bhot Khoriya and Deurali were 21.3°C and 21.5°C, respectively, and did not show large differences among the sites. Rainfall at Bhot Khoriya during the cropping season in 2018 was 973 mm, and rainfall could be assumed to be similar among the sites because they were located within 3 km of each other. Daily rainfall at Bhot Khoriya was measured using a rain gauge after each rainfall event and was presented in Figure 2. Moreover, the rainfall received at the sites is sufficient to ensure the normal growth of cauliflower. Although the sites are located at different altitudes, the farming practice was similar in all sites. The household economic status in Angare was observed to be the poorest among the three households with less technical knowledge about farming. The highest financial status was observed in the household of Deurali, which had more technical knowledge about farming and could afford chemical fertilizers and pesticides as needed. The experimental sites for 2017 are different from those for 2018 in order to avoid residual effects of the treatment and to minimize the cauliflower clubroot disease, which was common in most farms in the village. The soils of the experimental sites were classified as Dystric Cambisols (FAO and UNESCO 1977). Based on the soil particle distribution, the soil texture was classified as sandy loam, loam, and silty loam for Angare, Bhot Khoriya, and Deurali, respectively. The basic physicochemical properties of the soils where field experiments were conducted in 2017 and 2018 are presented in Table 1.

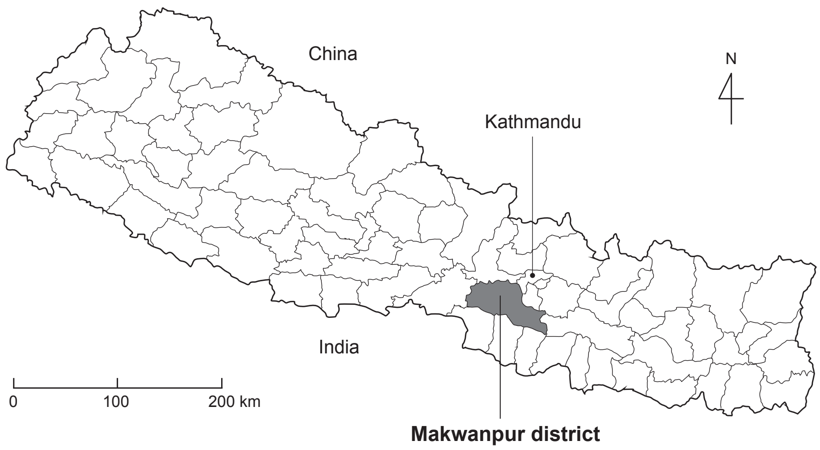

Figure 1. Location of the study area (Makawanpur district) in Nepal.

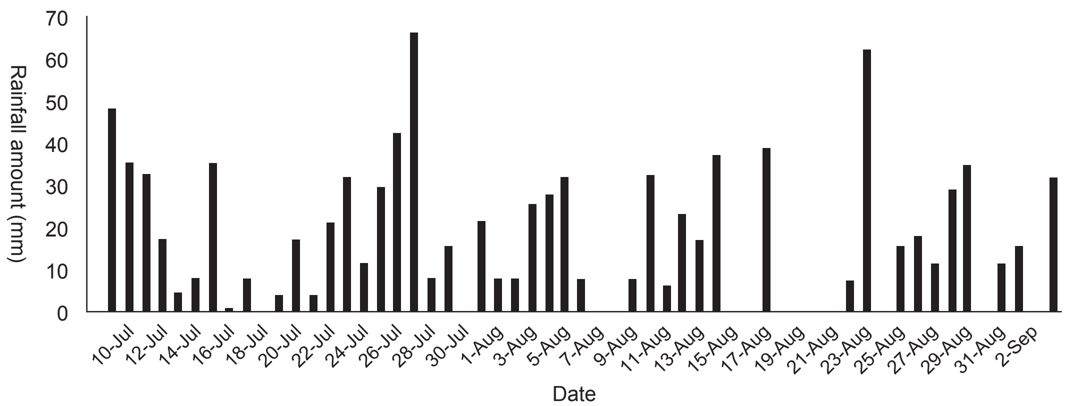

Figure 2. Daily rainfall event in study site (Bhot Khoriya) in year 2018.

Table 1. The basic physicochemical properties of soil collected before field experiment in year 2017 and 2018.

Particle size distribution (g kg^{-1} dry soil)	Value measured					
	Angare		Bhot Khoriya		Deurali	
Sand (0.05–2.0 mm)	597.2		346.3		213.8	
Silt (0.002–0.05 mm)	326.5		479.0		602.1	
Clay (< 0.002 mm)	76.3		174.7		184.1	
Chemical Properties	2017	2018	2017	2018	2017	2018
pH (H_2O)	6.93	5.69	5.18	5.16	5.27	5.10
EC (mS m^{-1} dry soil)	15.84	10.13	21.09	19.21	14.05	11.21
CEC (cmol$_c$ kg^{-1} dry soil)	10.01	7.90	14.76	18.83	13.88	18.32
Total N (g kg^{-1} dry soil)	1.89	1.24	3.18	2.47	2.26	2.22
Total C (g kg^{-1}dry soil)	20.80	18.53	33.44	37.09	25.57	35.47
Mineral N (mg kg^{-1} dry soil)	43.22	9.83	76.52	16.84	52.29	13.10
K (cmol$_c$ kg^{-1} dry soil)	0.32	0.28	0.26	0.27	0.29	0.33
Available P (g kg^{-1} dry soil)	0.69	0.69	0.59	0.89	0.29	0.61

Table 2. Composition of urine and ecosan manure used during field experiments.

Fertilizer type	Site	2017			2018		
		Total N	Total P	Total K	Total N	Total P	Total K
		g kg^{-1}					
Urine	Angare	2.8	0.8	1.3	2.7	0.8	1.3
	Bhot Khoriya	7.2	2.8	1.8	7.1	2.8	1.8
	Deurali	2.0	1.4	1.0	3.2	1.4	1.0
Ecosan manure		13.4	11.2	36.2	13.2	11.2	36.2

The urine needed for the experiment was collected from the ecosan toilet of each household. The urine collected in 100 L jar was used for the experiment and is considered to be the fresh urine. The ecosan manure from the ecosan toilets of these households was not ready to be used. Therefore, the necessary amount of ecosan manure for the experiment was collected from an ecosan toilet from another village (Gundu village of Bhaktapur district). The ecosan manure used in this experiment is the human faeces collected from the ecosan toilet. As a rule of the ecosan toilet, it was confirmed from the households that ash was sprinkled after every defecation and the excreta was ready to be used as a fertilizer with more than six months storage time. The urine and ecosan manure samples were collected for chemical analysis. Total nitrogen (TN) in the urine was determined by combustion catalytic oxidation method using a total organic carbon analyzer (TOC-LCSH; Shimadzu, Japan). Total phosphorus (TP) was determined calorimetrically using a spectrophotometer, and total potassium (TK) was determined using a flame photometer (AA-700; Shimadzu, Japan). TN in the ecosan manure was measured using ground samples using a high-temperature combustion method with a CN analyzer (EA IsoLink; ThermoFisher Scientific, USA). Dried ground ecosan manure samples were digested using a ternary mixture ($HClO_4$, HNO_3, H_2SO_4) for the determination of TP and TK as described by Effebi et al. (2019). TP was determined after color development following the ascorbic acid method. The intensity of the lines was evaluated by a detector (880 nm) in spectrophotometer (UVmini-1240; Shimadzu, Japan). TK was analyzed using atomic absorption spectroscopy (AA-700; Shimadzu, Japan). The N, P, and K contents of urine (calculated based on wet weight (g kg^{-1})) and ecosan manure (calculated based on dry weight (g kg^{-1})) used during the field experiment are listed in Table 2. The variation in N, P, and K in the urine from three households was due to variation in feeding habits and the amount of water consumed (Heinonen-Tanski and Wijk-Sijbesma 2005: 404). Only the TN concentration in the Bhot Khoriya urine (7.1 g L^{-1}) was found to be within the range (7.0–11.0 g L^{-1}) reported in the study of Karak and Bhattacharyya (2011, 402). Due to the variation in N concentration in urine among the households, N application in different treatments varied in 2017. The amount of urine needed to be applied in the later year (2018) was calculated based on the N present in urine in the former year (2017). Hence, in 2018, an equal amount of N was applied in the Chemical fertilizer (CF) and Urine (U) treatments. This led to the difference in the amount of N applied in the two years.

1.3. Experimental design

The experiment was laid out in a randomized complete block design. The total plot size was 75 m^2, and each plot was 2.5 × 2 m, consisting of five rows of 30 plants (Table 3, Figure 3). Each treatment was replicated three times. Hybrid seeds of the cauliflower (*Brassica oleracea*) variety 'White Shot' were used in this study. Cauliflower was chosen as a test crop because it can respond well to N. Since urine is rich in N, it was suggested to give priority to a crop that responds well to N (Jonsson et al. 2004: 17, 31). Cauliflower transplanting was performed four weeks after sowing with the following five treatments: Control (C), Chemical fertilizer (CF), Urine (U), Ecosan manure + Urine (E+U), and Ecosan manure (E). The rate of fertilizer application is presented in Table 4.

Table 3. Experimental setup.

Farm Site	Altitude	Total plot size	No. of replication	No. of treatment	No. of plants grown per treatment	Sampling interval of plants	No. of plants sampled per treatment
Angare	1,822 m	75 m^2	3	5	30	Sampling in three weeks Sampling at harvest	3 5
Bhot Khoriya	1,981 m	75 m^2	3	5	30	Sampling in three weeks Sampling at harvest	3 5
Deurali	2,125 m	75 m^2	3	5	30	Sampling in three weeks Sampling at harvest	3 5

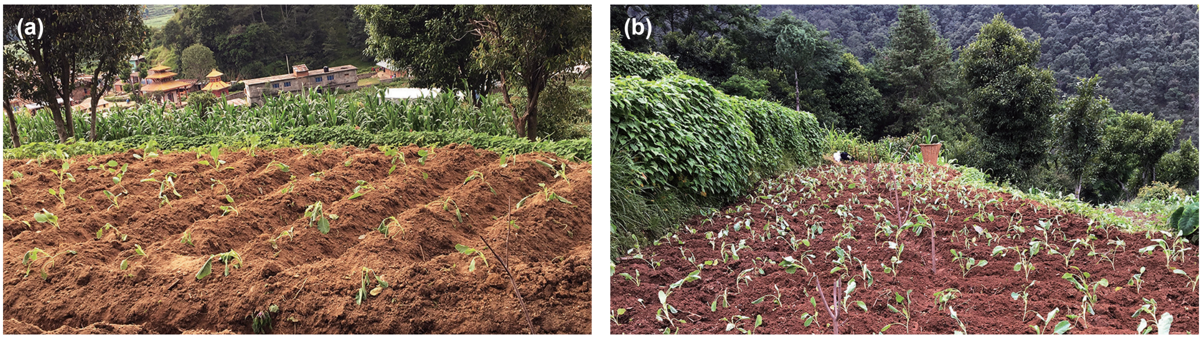

Figure 3. (a) Experimental site in Angare in year 2018. (Taken by the authors)
(b) Experimental site in Deurali in year 2018. (Taken by the authors)

Table 4. Fertilzer application rate in different treatments during field experiments.

Treatment	Application rate (kg ha^{-1})						Remarks
	2017			2018			
	N	P	K	N	P	K	
Angare							
C	0	0	0	0	0	0	
CF	90+90	17+17	0	90+90	17+17	0	Basal/ top dressing - Chemical fertilizer
U	35+35	10+10	16+16	90+90	26+26	42+42	Basal/ top dressing - Urine
E+U	90+35	74+10	242+16	90+90	74+26	242+42	Basal - Ecosan manure/ top dressing - Urine
E	45+45	37+37	121+121	45+45	37+37	121+121	Basal/ top dressing - Ecosan manure
Bhot Khoriya							
C	0	0	0	0	0	0	
CF	90+90	17+17	0	90+90	17+17	0	Basal/ top dressing - Chemical fertilizer
U	90+90	35+35	22+22	90+90	35+35	22+22	Basal/ top dressing - Urine
E+U	90+90	74+35	242+22	90+90	74+35	242+22	Basal - Ecosan manure/ top dressing - Urine
E	45+45	37+37	121+121	45+45	37+37	121+121	Basal/ top dressing - Ecosan manure
Deurali							
C	0	0	0	0	0	0	
CF	90+90	17+17	0	90+90	17+17	0	Basal/ top dressing - Chemical fertilizer
U	26+26	17+17	12+12	90+90	60+60	42+42	Basal/ top dressing - Urine
E+U	90+26	74+17	121+12	90+90	74+60	242+42	Basal - Ecosan manure/ top dressing - Urine
E	45+45	37+37	121+121	45+45	37+37	121+121	Basal/ top dressing - Ecosan manure

C: Control, CF: Chemical Fertilizer, U: Urine, E + U: Ecosan manure + Urine, E: Ecosan manure

Urea and diammonium phosphate (DAP) were applied in the CF treatment at a rate of 180 kg ha^{-1} N (according to the farmer's typical practice). The liquid form of urine collected from the ecosan toilet of each household was applied in U and as a top-dressing in E+U. The urine was applied by making a hole in the soil, as mentioned by Rodhe et al. (2004: 197), to avoid ammonia losses, and ecosan manure was applied in the periphery of the crop above the soil. The completely decomposed ecosan manure collected from the same ecosan toilet was applied as basal fertilizer in the E+U and E treatments at all sites. The amount of urine applied as a treatment in 2017 was calculated based on the assumption that 550 L of urine contains 4 kg of N (Esrey et al. 2001, 10) to make the application equivalent to the amount of N applied in the CF treatment. The amount of urine to be applied in the later year (2018) was calculated based on the N present in urine in the former year (2017). The fertilizer was applied in split doses (twice), basal (first application) and top-dressing (second application). The basal application was performed ten days after transplant, and the top-dressing was performed two weeks after the basal application. Weeds were controlled as necessary. Each "treatment" in this study can be regarded as a "scenario" that reflected the situation of the households who have the potential to apply urine and ecosan manure, because the amount of nutrients applied was different among the treatments and the nutrient application calculation was based only on the N concentration in urine.

1.4. Soil sampling and physicochemical analysis

The soil samples were collected twice, once prior to the experiment and again after the cauliflower was harvested (after the curds were judged to be mature), from the topsoil (0–15 cm) at all the sites. Five soil samples were collected per plot and homogenously mixed together to form a composite for each treatment. All soil samples were air-dried, ground and sieved using a 2 mm sieve to remove pebbles. Then, chemical analyses were conducted. The particle size distribution was determined by the pipette method (Gee and Bauder 1986: 383–384) and sieving for only one year, assuming that soil texture does not change under normal agricultural conditions. Soil pH was measured in a deionized water and potassium chloride (KCl) solution at a soil: solution ratio of 1 : 5 using a pH meter with a glass electrode (LAQUA F-74BW; Horiba, Japan). The exchangeable cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+}) were extracted using 1 mol L^{-1} ammonium acetate buffered at pH 7.0 and determined by atomic absorption spectroscopy (AA-700; Shimadzu, Japan) after extracting with 1 M ammonium acetate at pH 7.0. To determine the cation exchange capacity (CEC), the residual soil was washed with ethanol after ammonium acetate extraction, and the remaining ammonium (NH_4) was extracted with 10% sodium chloride (NaCl). The NH_4 concentration was determined by using a flow injection auto analyzer (Flow Analysis Method, JIS K-0170, AQLA-700 Flow Injection Analyzer; Aqualab INC., Japan). Total carbon (TC) and total nitrogen (TN) content was measured from ground samples, and the measurement was taken using the high-temperature combustion method with a CN analyzer (EA IsoLink; ThermoFisher Scientific, USA). Mineral N (NH_4-N and NO_3-N) was analyzed colorimetrically using FIA (details mentioned above) after extraction with 2 mol L^{-1} KCl. Avai. P determination was performed colorimetrically using molybdate by the Bray-2 method (Nanzyo 1997).

1.5. Plant sampling and analysis

Three cauliflower plants at three weeks after transplanting and five cauliflower plants at harvest per treatment were sampled from all the plots. The leaves and flowers of cauliflower at harvest were immediately separated after sampling and weighed to determine the fresh weight of cauliflower. The samples were then chopped into pieces and sub-sampled for further analysis. The sub-samples were oven dried at 70°C until they were completely dried. The samples were then weighed and homogenized using a rotating-disk mill. The dry weight taken was expressed on a per-hectare basis. For plant nutrient content analysis, dried samples were milled and digested using HNO_3.

Phosphorus concentration was determined by color development using molybdate. The concentrations of K, Na, Ca, and Mg were analyzed using atomic absorption spectroscopy (AA-700; Shimadzu, Japan).

1.6. Plant nutrient uptake and nitrogen use efficiency

Plant nutrient uptake was calculated separately for leaves and flowers and summed as a total. Nutrient uptake was calculated as shown in equation (1):

$$\text{Nutrient uptake (kg ha}^{-1}\text{)} = \text{nutrient content (\%)} \times \text{sample dry weight (kg ha}^{-1}\text{)}/100 \qquad (1)$$

The apparent N recovery efficiency (ARE) and agronomic N use efficiency (AUE) of cauliflower were calculated as shown in equations (2) and (3):

$$\text{ARE} = (\text{Nf} - \text{N0})/\text{N} \times 100 \qquad (2)$$

$$\text{AUE} = (\text{CauYf} - \text{CauY0})/\text{N} \times 100 \qquad (3)$$

where Nf = nitrogen uptake from fertilized plots (kg N ha^{-1}), N0 = nitrogen uptake from control plots (kg N ha^{-1}), CauYf = cauliflower yield from fertilized plots (kg cauliflower ha^{-1}), CauY0 = cauliflower yield from unfertilized plots (kg cauliflower ha^{-1}), and N = total nitrogen applied per hectare (kg N ha^{-1}).

1.7. Calculation and statistical analysis

The crop production parameters observed were dry weight (kg ha^{-1}) at three weeks and dry weight (kg ha^{-1}) of leaves and flowers at harvest using a digital scale. The data obtained were subjected to analysis of variance (ANOVA). Statistical analysis was conducted with IBM SPSS Statistics 20.0 (IBM, USA), where a significant difference was reported at the 5% probability level.

2. Results

2.1. Cauliflower biomass and yield

The mean values of dried biomass of cauliflower at the three experimental sites are presented in Table 5. The results indicated that in both years, the dried cauliflower biomass was significantly ($p < 0.05$) different among the treatments in Bhot Khoriya and Deurali, but no significant difference was observed in Angare either in three weeks or at harvest. Although the difference was not statistically significant, the dried cauliflower biomass at harvest in Angare was increased in the soils treated with U, E+U and E compared with that of the no-treatment control and was similar to the biomass from soil treated with CF. Furthermore, there were significant ($p < 0.05$) differences in biomass among the sites in 2018 (Figure 4), resulting in higher biomass in Angare than in Bhot Khoriya and Deurali. A similar growth trend for cauliflower was observed in Bhot Khoriya and Deurali in both years.

2.2. Nutrient uptake and N use efficiency

N, P, and K uptake by the plants and ARE and AUE in 2017 and 2018 are presented in Tables 6 and 7. A significant ($p < 0.05$) difference in N uptake was observed in Deurali in 2017, with less uptake by plants in the C treatment than by the plants grown with the other treatments (Table 6). In 2018, a significant ($p < 0.05$) difference in N uptake was observed in Bhot Khoriya, with the highest uptake by the plants grown in E+U treated soils and

Table 5. Mean values of dried biomass of cauliflower as affected by different treatments.

Treatment	2017				2018			
	Dried biomass (kg ha^{-1})							
	Sampled in three weeks	Sampled at harvest			Sampled in three weeks	Sampled at harvest		
		Leaves	Flower	Total		Leaves	Flower	Total
Angare								
C	77	604	184	788	82	1,105	292	1,397
CF	137	1,028	511	1,539	106	1,772	564	2,336
U	65	675	312	987	103	1,723	445	2,168
E+U	158	1,412	498	1,910	167	1,426	440	1,866
E	86	1,216	416	1,632	157	1,668	600	2,268
Bhot Khoriya								
C	200	811b	350	1,161	105b	549b	96b	645c
CF	219	949ab	424	1,373	144b	753ab	159ab	912bc
U	320	953ab	439	1,392	271a	1,249ab	282ab	1,531ab
E+U	238	1,383a	582	1,965	171ab	1,416a	541a	1,957a
E	186	1,301ab	600	1,901	168b	1,400a	338ab	1,738a
Deurali								
C	38b	379b	97b	476b	93	619b	83	702
CF	71ab	927ab	410ab	1,337a	176	887ab	151	1,038
U	97a	852ab	368ab	1,220a	136	991ab	123	1,114
E+U	99a	784ab	474ab	1,258a	183	1,296a	242	1,538
E	97ab	1,084a	669a	1,753a	163	888ab	290	1,178

C: Control, CF: Chemical Fertilizer, U: Urine, E+U: Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different for each site at $p < 0.05$

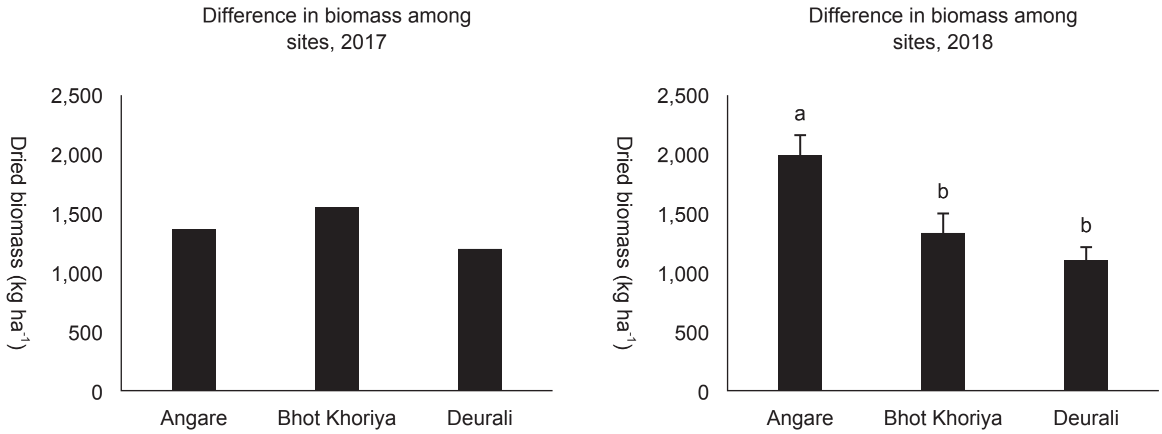

Figure 4. Difference in biomass among sites in year 2017 and 2018.

the least in the soils of the control treatment (Table 7). A significant ($p < 0.05$) difference in P uptake was observed in Bhot Khoriya and Deurali in 2017 for the plots with E and in Bhot Khoriya in 2018 for the plots with E and E+U (Table 7). K uptake was significantly ($p < 0.05$) different among treatments at all sites in 2018 (Table 7) and in Deurali in 2017 (Table 6). Both ARE and AUE at all sites were higher in 2017 compared to those in 2018 (Tables 6 and 7), with high AUE in 2018 at all sites in the soil treated with E.

Table 6. Effects of treatment on nutrient uptake and nitrogen use efficiency in 2017.

Treatment	Uptake by plant (kg ha^{-1})			Apparent N Recovery Efficiency (ARE)	Agronomic N Use Efficiency (AUE)
	N	P	K	%	%
Angare					
C	77.3	3.8	49.3	-	-
CF	162.4	9.4	126.3	47.3	4.1
U	81.4	4.8	84.7	5.9	2.8
E+U	142.1	10.3	143.3	51.8	9.0
E	117.4	10.2	120.4	44.6	9.4
Bhot Khoriya					
C	81.3	4.9c	73.8	-	-
CF	155.2	6.2bc	79.6	41.1	1.1
U	121.7	6.5bc	100.9	22.4	1.3
E+U	159.3	10.3ab	160.8	43.3	4.5
E	133.7	11.1a	147.9	58.2	8.2
Deurali					
C	27.1b	2.1b	18.2b	-	-
CF	127.9a	6.7ab	62.0ab	56.0	4.8
U	87.2a	6.5ab	77.5ab	115.6	14.3
E+U	89.1a	5.2ab	104.8ab	53.4	6.7
E	110.1a	9.9a	133.1a	92.2	14.2

C: Control, CF: Chemical Fertilizer, U: Urine, E+U: Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different for each site at $p < 0.05$

Table 7. Effects of treatment on nutrient uptake and nitrogen use efficiency in 2018.

Treatment	Uptake (kg ha^{-1})			Apparent N Recovery Efficiency (ARE)	Agronomic N Use Efficiency (AUE)
	N	P	K	%	%
Angare					
C	44.2	8.7	45.0b	-	-
CF	93.5	13.6	55.1b	27.4	4.0
U	71.5	13.9	60.9b	15.2	3.1
E+U	62.7	13.6	66.9b	10.3	1.1
E	72.6	14.8	116.3a	31.6	8.8
Bhot Khoriya					
C	21.1b	3.4b	14.3b	-	-
CF	39.2ab	6.6ab	28.6b	10.1	1.3
U	54.2ab	10.3ab	45.3b	18.4	4.7
E+U	64.9a	12.4a	112.8a	24.3	7.1
E	54.5ab	12.4a	76.5ab	37.1	11.7
Deurali					
C	24.2	3.3	19.4b	-	-
CF	51.8	4.6	36.8b	15.3	1.9
U	40.0	5.3	30.7b	8.8	2.3
E+U	52.7	7.7	58.8ab	15.8	4.6
E	44.9	6.9	88.6a	23.0	5.3

C: Control, CF: Chemical Fertilizer, U: Urine, E+U: Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different for each site at $p < 0.05$

Table 8. Na concentrations in leaves and flower of cauliflower after treatment in two years.

Treatment	2017		2018	
	Leaves	Flower	Leaves	Flower
	g kg^{-1} dry weight			
Angare				
C	1.02	1.22	3.42	2.15
CF	0.97	1.89	2.53	1.94
U	1.75	2.02	4.38	3.72
E+U	1.34	2.08	2.99	2.54
E	1.64	2.57	2.41	2.05
Bhot Khoriya				
C	2.09ab	2.73ab	3.32	3.28ab
CF	0.82b	2.41ab	3.32	2.71ab
U	3.09a	4.96a	6.58	4.24a
E+U	2.00ab	2.88ab	4.59	2.53b
E	2.54ab	2.34ab	4.38	2.72ab
Deurali				
C	1.32	2.54	3.61	1.78
CF	0.78	1.75	1.87	1.28
U	3.24	0.68	3.89	2.77
E+U	2.59	2.19	3.76	3.07
E	2.88	2.24	2.71	1.66

C: Control, CF: Chemical fertilizer, U: Urine, E+U: Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different at $p < 0.05$

2.3. Na uptake by the plants

A significant ($p < 0.05$) difference among treatments in Na uptake by plants in 2017 and 2018 was observed for Bhot Khoriya (Table 8), with the highest Na uptake both in the leaves and flowers obtained in the urine treatment. Although the difference in Na uptake among treatments at other sites was not significant, the highest Na uptake was observed in plants grown in the urine treatment.

2.4. Physicochemical characteristics of soil after treatment

Significant ($p < 0.05$) differences in soil pH, EC, and NO_3-N among treatments were observed only for Bhot Khoriya in 2017 (Table 9) and for all sites in 2018 (Table 10). The soil treated with CF showed a significant decrease in soil pH, whereas in the soil treated with U and E treatments, a significant increase in soil pH was recorded compared to the pH of the control soil (Tables 9 and 10). Soil NH_4-N increased, and soil NO_3-N decreased as an effect of all treatments at harvest compared to those levels in the control (Tables 9 and 10). No significant difference in soil exchangeable cations at any site was observed in 2017 (Table 11). It was observed that exchangeable magnesium and exchangeable potassium were significantly different among the treatments in Bhot Khoriya, and exchangeable calcium and exchangeable sodium were significantly different among the treatments in Deurali in 2018 (Table 11).

Table 9. Effects of treatment on soil chemical characteristics in three sites in year 2017.

Treatment	Soil chemical characteristics after harvest				Change in soil chemical characteristics after harvest			
	Soil pH	EC	NH_4-N	NO_3-N	Soil pH Increase	EC Decrease	NH_4-N Increase	NO_3-N Decrease
		mS m^{-1} dry soil	mg kg^{-1} dry soil			mS m^{-1} dry soil	mg kg^{-1} dry soil	
Angare								
C	7.29	11.97	6.41	13.16	0.41	3.80	2.05	6.75
CF	7.03	11.07	6.03	14.25	−0.72	4.58	1.70	8.21
U	7.22	10.47	5.65	12.41	−0.01	5.37	1.75	6.76
E+U	7.17	11.91	6.28	13.50	0.30	3.61	−0.11	7.21
E	7.01	11.35	8.28	20.75	0.13	4.34	3.06	12.46
Bhot Khoriya								
C	5.51a	6.94	9.78b	13.66	0.24a	14.15	0.53ab	70.63a
CF	5.19b	10.74	9.18b	36.08	0.05bc	10.35	−1.93b	16.96b
U	5.27ab	6.51	10.75ab	17.16	0.13abc	14.58	0.91ab	36.75ab
E+U	5.28ab	7.50	10.15ab	21.66	−0.03c	13.59	−1.51b	34.16ab
E	5.25ab	7.81	11.80a	18.58	0.19ab	13.28	4.23a	67.50a
Deurali								
C	5.45	5.67	9.86	10.83	0.19	8.20	−3.56	27.33
CF	5.22	7.13	10.08	30.83	−0.11	6.89	−1.10	8.83
U	5.34	5.97	9.13	12.41	0.07	8.07	−2.63	31.83
E+U	5.49	6.08	8.36	11.66	0.24	7.94	−4.16	29.58
E	7.59	6.26	8.63	10.91	0.27	7.74	−3.88	25.75

C: Control, CF: Chemical Fertilizer, U: Urine, E+U: Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different for each site at $p < 0.05$

Table 10. Effects of treatment on soil chemical characteristics in three sites in year 2018.

Treatment	Soil chemical characteristics after harvest				Change in soil chemical characteristics after harvest			
	Soil pH	EC	NH_4-N	NO_3-N	Soil pH Increase	EC Decrease	NH_4-N Increase	NO_3-N Decrease
		mS m^{-1} dry soil	mg kg^{-1} dry soil			mS m^{-1} dry soil	mg kg^{-1} dry soil	
Angare								
C	5.98a	6.74b	3.70	2.41b	0.11a	3.30c	1.35	7.58a
CF	5.35b	12.81a	4.55	8.91a	−0.30b	−2.32d	1.38	−3.41b
U	5.59ab	4.40b	2.98	1.43b	−0.16b	5.54a	0.65	7.23a
E+U	5.78ab	5.89b	7.30	1.80b	0.16a	4.21b	4.81	4.36ab
E	5.86ab	6.26b	3.36	1.90b	0.28a	3.85bc	0.70	3.93ab
Bhot Khoriya								
C	5.58a	6.59b	8.13	7.26	0.39a	12.20a	2.18	2.98
CF	4.88b	25.60a	10.10	9.96	−0.21b	−6.22c	4.98	0.20
U	5.35a	5.81b	7.30	2.26	0.18ab	12.92a	−0.26	7.98
E+U	5.67a	8.95b	6.31	2.50	0.39a	10.50b	0.68	11.41
E	5.59a	8.24b	6.20	2.13	0.26a	10.97b	0.78	7.78
Deurali								
C	5.53a	4.22b	0.63b	1.86	0.34a	6.95a	1.86	6.11
CF	4.93b	14.78a	7.60a	4.96	−0.15b	−3.55d	4.96	2.90
U	5.48a	4.34b	0.73b	1.63	0.33a	6.91a	1.63	8.01
E+U	5.58a	5.28b	1.10b	2.48	0.53a	5.95b	2.48	8.40
E	5.68a	7.62b	0.70b	3.06	0.58a	3.72c	3.06	7.71

C: Control, CF: Chemical Fertilizer, U: Urine, E+U:Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different for each site at $p < 0.05$

Table 11. Effects of treatment on soil exchangeable cations in two years.

Treatment	Soil chemical characteristics after harvest							
	2017				2018			
	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	Ex. Ca	Ex. Mg	Ex. K	Ex. Na
	$cmol_c$ kg^{-1} dry soil							
Angare								
C	10.27	1.55	0.34	0.05	5.91	0.90	0.24	0.10
CF	9.01	1.07	0.25	0.08	4.69	0.72	0.21	0.11
U	9.80	1.62	0.45	0.18	4.47	0.60	0.15	0.13
E+U	8.93	1.27	0.62	0.04	5.00	0.79	0.28	0.13
E	8.94	1.46	0.23	0.11	5.06	0.91	0.27	0.10
Bhot Khoriya								
C	4.47	0.97	0.34	0.08	7.27	1.59abc	0.20ab	0.10
CF	3.78	0.73	0.25	0.06	6.01	1.10bc	0.23ab	0.12
U	4.20	0.74	0.49	0.12	5.88	1.00c	0.14b	0.12
E+U	3.85	0.67	0.20	0.10	6.94	2.11a	0.46a	0.17
E	3.74	0.70	0.32	0.15	7.42	1.89ab	0.38ab	0.13
Deurali								
C	4.36	0.87	0.53	0.07	4.86ab	0.79	0.20	0.10b
CF	3.88	0.58	0.29	0.05	3.64b	0.60	0.22	0.07b
U	3.76	0.51	0.18	0.10	4.60ab	0.78	0.22	0.11b
E+U	3.52	0.80	1.09	0.17	4.74ab	1.11	0.63	0.19a
E	4.14	0.79	0.84	0.11	5.84a	1.14	0.60	0.09b

C: Control, CF: Chemical Fertilizer, U: Urine, E+U: Ecosan manure + Urine, E: Ecosan manure
Means within each column followed by same letter or none at all are not significantly different for each site at $p < 0.05$

3. Discussion

3.1. Effects of the treatments on cauliflower yield

The household economic statuses and farming skills among the three households were different; the highest were observed in Deurali, followed by Bhot Khoriya and Angare. Clubroot disease was observed less in Angare than in Bhot Khoriya and Deurali. These might have fundamentally affected the treatment effect on growth performance among the sites. Additionally, the difference in soil particle distribution and residual effects on soil from previous farming practices might have some effects on the treatment of the present study. However, in the present experiment, although there were altitudinal differences among the sites (Angare: 1,822 m, Bhot Khoriya: 1,981 m, Deurali: 2,125 m above sea level), the climate and rainfall pattern at all sites was assumed to be similar and to have no particular effect on the treatment. The urine and ecosan manure used in the field experiment contain appreciable levels of nutrients (Table 2). This reflects that urine and ecosan manure can be essential sources of plant nutrients and soil conditioners for agriculture. However, the variation in N, P, and K concentration in the urine among the households (Table 2) caused variation in the treatment among the sites and between the years. This resulted in the variation in the growth and yield during the harvest.

The similar growth of cauliflower from the soil treated with U, E+U or E in this study (Table 5) indicates that human urine and ecosan manure are good sources of plant nutrients, confirming the results from other countries such as South Africa, Zimbabwe (Guadarrama et al. 2001: 1–2), Finland (Pradhan et al. 2007: 8659; 2010: 2036). Fertilization treatments increased the growth of cauliflower at all sites in both years, but a significant increase at harvest was observed in E and E+U in 2018 in Bhot Khoriya (Table 5). In Angare, although there was no significant difference in the dry biomass of cauliflower in both years, cauliflower growth was accelerated due to fertilizer application by 48%, 20%, 58% and 51% in the CF, U, E+U and E treatments, respectively, in 2017 and by 40%, 35%, 25% and 38% in the CF, U, E+U and E treatments, respectively, in 2018 compared to growth in the control treatment; these results demonstrate the positive effects of urine and ecosan manure as soil amendments. The amount of nitrogen that was supplied by CF at all sites was 180 kg ha^{-1} in 2017, while the amounts supplied in the U, E+U and E treatments were 61%, 30% and 50% lower in Angare, 0%, 0% and 50% lower in Bhot Khoriya and 71%, 35% and 50% lower in Deurali, respectively, than that in CF (Table 4). The amount of nitrogen applied in the U and E+U treatments in both years was the same. Increased or comparable growth patterns were seen with U, E+U and E treatments because of the increased nutrient availability from the higher supply of P and K that was applied through urine and ecosan manure in U, E+U and E than through CF (Table 4) or from improvements in the soil quality even though the amount of nitrogen applied was relatively small. This result is similar to the situation with increased maize production due to the improvement in water productivity from faeces + urine (Guzha et al. 2005: 844). The nutrient content in urine is easily accessible, as it is in liquid form, but the nutrient contents in ecosan manure release more slowly and might have an effect at later stages of crop growth.

In 2018, although the same amount of N in the CF, U, E+U and E treatments was applied at all three sites (Table 2), no significant difference in dried biomass among the treatments in Angare was observed (Table 5). This might be the result of N loss from urine either by volatilization or leaching and the slow release of nutrients in the E+U and E treatments. The amount of urine applied in 2018 was higher compared to that applied in 2017 to make the N concentration equivalent in all treatments, which might have resulted in more N loss in 2018 than in 2017. This result is similar to the result from Di and Cameron (2007: 289), who reported significant NO_3-N losses as the amount of urine nitrogen application increased. This result suggests that the application of urine in moderate amounts (26 kg ha^{-1}–35 kg ha^{-1}) might be beneficial for minimizing NO_3-N losses and improving productivity. It is also likely more convenient to farmers to minimize the workload of transporting urine onto the farm. Additionally, urine collected from ecosan toilets could be utilized across large farm areas, making ecosan toilets feasible for fertilizer use. The possibility of N volatilization and leaching from urine increases the risk of N being unavailable to plants. Another possibility for poor crop performance in Angare (especially in soil treated with U) might be the result of heavy rainfall and more flooding, especially due to the high sand content (597 g kg^{-1} dry soil) in the soil in comparison to the sand content in the soils of Bhot Khoriya (346 g kg^{-1} dry soil) and Deurali (213 g kg^{-1} dry soil) (Table 1). The study on the effect of urine, poultry manure and dewatered fecal sludge conducted by Amoah et al. (2017: 11) in Ghana in the dry and rainy seasons showed poor plant growth and low yields in the rainy season compared to those in the dry season. Hence, our study results show similarity to those in the study by Amoah et al. (2017: 11), as we observed poor plant growth and low yields when the study conducted in the rainy season. The growth of cauliflower in all treatments was higher in both years in Angare compared to that in the other sites (Table 5) and showed significantly ($p < 0.05$) higher biomass in Angare among the sites in 2018 (Figure 4). This might be the result of the lesser effect of clubroot disease compared to that in Bhot Khoriya and Deurali. These results demonstrate that mineral fertilizer or nutrients applied through urine and ecosan manure lead to better crop performance. It can also be concluded that applying urine either in combination with ecosan manure or with other organic manure is much more effective than applying urine alone.

3.2. Effect of nutrient uptake and utilization by cauliflower

The study conducted by Kutu et al. (2010) revealed that N uptake by plant increase with the increase in the proportion of urine-N in the human faeces/urine combinations treatment. The highest N uptake in the solo urine treatment followed by treatments with greater proportion of urine-N was due to the readily available N contained in the urine. In contrast to this, our study showed that the N uptake by plants in 2017 at all sites was higher than the

N uptake by plants in 2018, although more N through urine was applied in 2018 (Tables 6 and 7). This might be because nitrogen applied in the later year was not fully taken up by the plant and could not contribute to the growth of the plant. This result of low N uptake is in agreement with the finding that if a moderate amount of urine fertilizer is carefully incorporated directly into the soil at the correct time, urine nitrogen has the same agricultural values as the nitrogen in commercial mineral fertilizers (Richert-Stintzing et al. 2010: 47–50). ARE was higher in all sites in 2017 than in 2018, ranging from 5.9%–115.6% in 2017 and from 8.8%–37.1% in 2018 (Tables 6 and 7). No significant difference among treatments was observed in ARE in either year, whereas AUE varied among treatments (Tables 6 and 7). The AUE values in the E+U treatment (9.0, 4.5, and 6.7 in 2017 and 1.1, 7.1, and 4.6 in 2018 in Angare, Bhot Khoriya and Deurali, respectively) and the E treatment (9.4, 8.2, and 14.2 in 2017 and 8.8, 11.7, and 5.3 in 2018 in Angare, Bhot Khoriya and Deurali, respectively) were higher than those of the CF and C treatments in both years. This result reveals that N uptake by plants grown in CF did not contribute to plant growth as much as the nitrogen taken up in the E+U and E treatments. The high AUE in plants grown in soil treated with E+U, E and U suggests the potential of using urine and ecosan manure as a fertilizer. The lack of a consistent increase in yields from increased N application suggests that N is not the only factor limiting the growth of cauliflower.

P uptake by plants was significantly ($p < 0.05$) higher in the E treatment than in the other treatments in Bhot Khoriya in both years (Table 6) and in Deurali in 2018 (Table 7), but there was no significant difference among treatments in P uptake by plants in Angare. This result is similar to the study conducted by Kutu et al. (2010) who showed that higher P uptake by plants was from the treatments treated with high proportion of human faeces. Although there was no significant difference in P uptake by plants in Angare in both years and in Deurali in 2018, P uptake by plants in the U-, E+U- and E-treated soil was comparatively higher than that in the soil with no treatment (Tables 6 and 7). Phosphorus was applied during the experiment through DAP in the CF treatment and through urine and ecosan manure in U, E+U and E. The amount of P applied in the E treatment was almost double the amount applied via CF (Table 4), since the application rate was based on N content. This might be the reason for the high uptake of P in E-treated soil. The observed result indicates that P is another important nutrient for cauliflower growth, in addition to N. If enough P was added, the biomass and P uptake could have been higher. This finding also agrees with the results on cauliflower reported by Cutcliffe and Munro (1976: 128–130) and the results on spinach reported by Kutu et al. (2010). Another study revealed that the uptake of phosphorus from urine during the first growth year was 12% higher than that from mineral fertilizers (Kirchmann and Pettersson 1994: 153).

Significantly ($p < 0.05$) higher K uptake by plants in E-treated soil than in the other treatments in Deurali in 2017 and at all sites in 2018 (Tables 6 and 7) might be due to the high concentration (36.26 g kg^{-1} dry soil) of K in human ecosan manure (Table 2). This result shows that applied K might have some effect on the increased yield of cauliflower. Increased cauliflower yields due to K application compared to yields under no K application were reported by Cutcliffe and Munro (1976: 130). The significantly ($p < 0.05$) higher Na concentration (almost 50% higher than that in the control treatment) (Table 8) in the leaves and flowers of cauliflower grown in U-treated soil in Bhot Khoriya was due to the high Na concentration in urine. Although there was no significant difference in Na concentrations among the plants at other sites, it is worth mentioning that the concentration was higher in the plants from the U-treated soil than in the plants from the other treatments (Table 8). This could lead to a soil salinity problem in the long term. The EC in the soil doubled in the urine + poultry dropping treatment studied by Amoah et al. (2017).

3.3. Effect of treatment on soil characteristics and soil N status

Compared to 2018, soil pH in Angare in 2017 before treatment was higher. The reason behind this is that the experimental farm used in two years was different to minimize the residual effect of the treatment and club root effects in cauliflower. Less technical knowledge about farming, improper management of farm sites and previous crop grown might have caused higher soil pH in year 2017. Similar to the effect seen in other studies, CF treatment acidified the soil, whereas soil pH was significantly ($p < 0.05$) increased by 0.16–0.58 compared to that of the control as a result of urine and ecosan manure application at all sites in 2018 (Table 10). The lack of a significant increase in soil pH in 2017 (Table 9) might be due to the lower amount of urine and ecosan manure applied as a treatment. The decrease in soil pH in both years in CF ranging from 0.01–0.72 demonstrates the acidification of soil by urea fertilization. EC decreased in the soil after harvest in all treatments except for the chemical fertilizer treatment in 2018. Adeoluwa and Cofie (2012: 293) and Adeoluwa et al. (2015: 8) reported improvements to fertility and the general conditions of the soil after urine application, indicating its potential as a soil treatment. Many studies have reported a significant increase in soil NO_3-N as a result of urine application. This study, in contrast, showed that the decrease in NO_3-N concentration might be due to the low concentration of NO_3-N in the soil at the initial stage (Tables 9 and 10) and might be due to the loss of NO_3-N through volatilization and leaching into the environment. In 2017, it was observed that ARE was higher in all treatments at all sites than in 2018 (Tables 6 and 7). Although ARE was higher in the soil, it could not contribute to the overall growth of the plant. The study was carried out in the rainy season, and the soil was wet due to the rain falling every day (Figure 2). The amount of urine applied in 2018 was much higher in volume compared to that in 2017. This resulted in an overflow of urine, which contributed to volatilization and leaching, despite the urine being applied by making a hole in a soil, as mentioned by Rodhe et al. (2004: 197). This result also suggests applying less urine to minimize volatilization and leaching. The exchangeable cations in the soil were not significantly different among the treatments in 2017 (Table 11). However, exchangeable calcium and exchangeable sodium were significantly increased in the E- and E+U-treated soils, respectively, in Deurali after treatment compared to those of the control (Table 11). Both exchangeable magnesium and exchangeable potassium were significantly increased in E+U-treated soil in Bhot Khoriya after treatment compared to those of the control (Table 11). The lack of a significant increase in exchangeable cations in 2017 might be due to the lower amount of N applied in the U and E+U treatments. This result suggests that urine and ecosan manure applied as fertilizer might have some effect on the soil. The nonsignificant differences in some soil characteristics after treatment (Tables 9, 10 and 11) could be related to the short period of cultivation, the experiment being conducted in the rainy season and the past land use practices. Therefore, further long-term cultivation studies are still needed to monitor the continuous effects of urine and ecosan manure on soil fertility together with leaching phenomena.

Conclusion

The results of this study suggest that urine combined with ecosan manure could be applied to the soil as fertilizer to improve the soil nutrient status and the agronomic yield parameters of cauliflower. Human urine and ecosan manure, which are seen as waste and as an environmental nuisance, could be harvested and used as fertilizer. Thus, the dependency on chemical fertilizer could be reduced. Human urine performed better in terms of improving soil fertility (increasing soil pH), while human ecosan manure might have residual effects on successive crops and is good for soil with both low and high nutrient contents. The application of a moderate amount of urine at least twice is recommended for vegetable production. The application of urine in combination with ecosan manure might have a more significant effect on crop growth than the application of urine alone. Further research in different locations, different soils, and different seasons with different crops is necessary to address the issue of low N recovery and to increase soil fertility.

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