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## Peeing out of poverty? Human fertilizer and the productivity of farming households

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*Peeing out of poverty? Human fertilizer and  
the productivity of farming households.*

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PEEING OUT OF POVERTY? HUMAN FERTILIZER AND  
THE PRODUCTIVITY OF FARMING HOUSEHOLDS

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# Peeing out of poverty? Human fertilizer and the productivity of farming households.\*

Jan Pettersson<sup>†</sup> and Johan Wikström<sup>‡</sup>

January, 2013

In many parts of the world, soils poor in nutrients are farmed with little addition of fertilizer, further depleting the farmland. The very same farmers often face poor sanitary solutions. So-called ecological sanitation aims at providing sanitation and at recycling nutrients as fertilizer. This human fertilizer may act as a substitute for artificial fertilizers (improving the household budget) or as a complement (improving soil quality, increasing agricultural yields).

We collected demographic, economic and farming data from 618 households in southern Mali, of which 155 benefitted from an ecological sanitation investment program. We do not find any support for human fertilizer being used complementary, although the effect on yields varies over crops. Instead, we find that beneficiary households substitute artificial fertilizer with human fertilizer at 10 to 15 per cent of the average household use of artificial fertilizers. While our results imply small economic incentives at the household level for investing in ecological sanitation, we do not account for health effects at the household or community level.

**JEL Classification:** D13, O12, O13, Q12

**Keywords:** Household Productivity, Ecological Sanitation, UDDT, Mali, Fertilizer, Matching

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# 1 Introduction

Lack of proper sanitation is a killer. Diarrhoeal diseases are one of the most common causes of death for children in the world, which to a large extent could be prevented by access to adequate sanitation facilities. Bad sanitation is also wasteful. Human excrements contain the most important nutrients necessary for plants to grow and tend to end up in rivers, leading to eutrophication, instead of being used productively. The economically poorer the farming context, the larger is the challenge of ensuring a non-negative soil nutrient balance through the addition of (costly) artificial fertilizers. In the extreme, farming without fertilization depletes the soil from nutrients beyond restoration possibility.

Sanitary solutions that also aim at recycling nutrients are generally referred to as ecological sanitation (EcoSan, for short). By providing human fertilizer, such solutions add a private economic incentive for investment in sanitation. For farming households, this may imply either a decrease in the use of artificial fertilizers (using human fertilizer as a substitute) or an increase in the total amount of fertilizer (using human fertilizer complementary). With respect to the challenges of soil depletion and sanitation, EcoSan has been studied surprisingly little from an economic perspective. To our knowledge, this is the first article using household data to study effects of EcoSan on farming household's productivity. We evaluate an EcoSan project in Mali, where just over 150 beneficiaries got an urine diverting dry toilet (UDDT) installed.

Our first results consist of estimations of the potential value of human fertilizer in agriculture. An average household in our study is calculated to be able to produce around a fourth of its yearly expenditures on artificial fertilizers, corresponding to a yearly addition of nutrients or a yearly reduction in expenditures of about 50 Euro. Second, measuring the nutrient content of human fertilizer in a selected sample of beneficiaries, we note that the quantity and quality of human fertilizers actually retained is only a fraction of

this potential amount. Turning to the (treatment) effects on yields and use of artificial fertilizers, we do not find any support for human fertilizer being used complementary, although the effect on yields varies over crops. Instead, we find that households with an EcoSan solution substitute artificial fertilizer with human fertilizer at 10 to 15 per cent of the average household use of artificial fertilizers, despite the indication of a much lower level of nutrients recycled.

The paper proceeds as follows. The next section presents the motivation behind ecological sanitation in more detail. Section 3 describes the program studied in this paper which is followed by a section on our data used. In section 5, we calculate the theoretical as well as the actual value of human fertilizer used, and discuss the economic incentives for private investments in this type of solutions. Section 6 sets up our empirical model and results on program impacts are found in sections 7 and 8. Section 9 concludes.

## **2 Ecological sanitation - problems addressed and previous studies**

Inappropriate handling of human excreta often leads to bacteria ending up in food and in water used for drinking and washing. Since there are several and interlocking reasons for diarrhoeal diseases it is hard to assess exactly how much of the diseases that are a direct consequence of improper sanitation. Nevertheless, some 4,900 children die each day because of diarrhoeal diseases, which in many cases could be prevented by access to adequate sanitation facilities (UNDP, 2006). In addition to mortality, about 5.6 billion working days and 443 million school days per year are lost as a result of diarrhoeal diseases caused by inadequate sanitation and improper water (Hutton and Haller, 2004). In a study of four Asian countries (Cambodia, Indonesia, the Philippines and Vietnam) The World Bank (2008) estimates the economic losses resulting from poor sanitation to average 2 per cent of GDP of which

the largest part concerns health effects. Waddington et al. (2009) provides a review of the literature on various interventions to reduce diarrhoea. The Millennium Development Goal target for drinking water has already been met while the target of halving the proportion of people lacking access to adequate sanitation will not be achieved as 2.5 billion people still live without improved sanitation (WHO and UNICEF, 2012).

The farming of poor soils is another urgent development challenge. The absence of agricultural productivity growth in African agriculture is arguably the strongest manifestation of this problem. In 2010, cereal yields per hectare averaged 1.3 tons for Sub-Saharan Africa (SSA) compared to 4.6 tons in East Asia and the Pacific (EAP) and 3.9 in Latin America and the Caribbean (LAC). Comparable figures in 1961 for SSA, EAP and LAC were 0.8, 1.4, and 1.3 evidencing not only low yields today but also stagnant growth in SSA (statistics from World Development Indicators). A large fraction of cultivated soils in Sub-Saharan Africa is less fertile compared to many parts of the world that have experienced a green revolution (see e.g. Voortman et al., 2003, on Africa's unfavorable biophysical environment and a comparison with Asia). High variability in rainfalls, low investments in irrigation and high levels of soil erosion are further hurdles for productivity increases (Kelly, 2006). Henao and Baanante (2006, table 6) reports the soil nutrient mining (the net removal of nitrogen, N, phosphorous, P, and potassium, K) to be very high; more than 85 per cent of African farmland have a rate of over 30 kilograms NPK per hectare and 40 per cent have rates over 60 kilograms. A reversal of this process through promotion of fertilizer use and soil conservation practices is a necessary condition to improve crop yields. The estimated requirement of NPK taken together for SSA is estimated to 6,776,390 tons (Henao and Baanante, 2006, table 11). In 2009, the sum of own production and net imports of NPK amounted to just under 2 million tons (data from the FAO statistics fertilizer module). On average, agriculture in SSA uses around 9kg of nutrients per ha compared to 73 in Latin America and 100-135 in Asia

(Kelly, 2006).

One reason for the insufficient use of fertilizer in SSA is the high costs of fertilizers, mainly due to high transportation cost and non-existent local production. There are however additional explanations why farmers would end up underinvesting in fertilizers. In a study of farmers in Western Kenya, Dufflo et al. (2011) show the use of fertilizers to be highly profitable and provide an explanation of inefficient levels of utilization in a behavioral model based on procrastination. Farmers defer investments in fertilizer until the last moment possible and may then fail to invest or underinvest in fertilizer. Small pre-seasonal discounts may therefore make farmers incur the cost of fertilizer just after harvest, when liquidity constraints are small. Inefficient use of fertilizers may also occur when households have limited capacities to smooth consumption and when shocks to consumption have long-lasting effects. Even though the use of fertilizer increases average yields, the variability of yields typically increases as well so the higher average returns are not large enough to outweigh the downward risk. Hence, not using fertilizers may be a deliberate risk-reducing, low return strategy, perpetuating poverty (e.g. Deacon and Christiaensen, 2011). Insurance schemes and drought resistant varieties are suggested to be viable policies to increase the use of fertilizer.

Ecological sanitation (EcoSan) is a general expression for sanitation systems aiming at creating adequate sanitation while at the same time recycling nutrients in order to reduce the need of artificial fertilizer (see Langergraber and Muellegger, 2005, for a general introduction into principles and concepts of EcoSan). The three major nutrient components of artificial fertilizer are nitrogen (N), phosphorus (P) and potassium (K) which all are taken up by plants and later eaten by humans, both through vegetal and animal foodstuffs. The same amounts of these nutrients that are consumed are also excreted, except for a small percentage that is absorbed by the body during childhood while muscles and bones are still growing. This means that, in addition to the health effects of adequate sanitation, there is a potential direct



economic gain through savings on artificial fertilizers or through increased returns to farming. This may impact on farmers' propensity to install facilities and somewhat brake the taboo related to the subject. Hence, EcoSan facilities in places where people lack proper sanitation and are engaged in agriculture have the possibility of addressing both a health dimension (absence of sanitation) and an economic dimension (soil depletion, return to farming). The production, storage and application of human fertilizer do involve some costs throughout the year. However, these costs are in terms of man-hours and do not involve any recurrent monetary outlays. The majority of handling costs is also associated with the regular maintenance of the toilet. Since the production of human fertilizer is an on-going process, through accumulation over time, present bias would at most lead to a smaller use of fertilizer since every deferral is directly linked to a proportional loss of potential fertilizer. The use of human fertilizer thus implies a close to free addition of nutrients in agriculture, an inexpensive method to increase average yields by making fertilizer use a less risky activity. Human fertilizer may therefore work as an insurance mechanism, minimizing the downward risk of fertilizer adoption. The essential question is whether the quantity of human fertilizer is enough to make any difference in practice. We address this question in section 5. While it is hard to think of the recycling of nutrients to be sufficient to restore depleted farmland, we argue that it has the potential to positively affect yields, in particular for small scale farming households.

There are very few studies of the economic impact of EcoSan investments. Guzha et al. (2005) find a positive effect on maize production when exhausted soils are restored by sanitized human excreta. Schuen et al. (2009) compare the economic viability of EcoSan with conventional sanitation systems using case studies from three countries (Burkina Faso, South Africa and Uganda). The main conclusion is that a scaling-up of EcoSan is unlikely without considerable external support. While there is no research known to us that explicitly studies the health effects of EcoSan, Niwagaba et al. (2009) and

Nordin et al. (2009) note the importance of accurate treatment of faeces in order to avoid diseases and to assure that the sanitation process produces safe fertilizers.

### **3 The program and its context**

In Mali, only 22 percent of the population use adequate sanitation facilities and 14 percent practice open defecation, which means that they depend on buckets, bushes, the banks of a stream, a back street or some other sheltered place for their daily several excretions (WHO and UNICEF, 2012). For families in rural Mali who are engaged in small size farming that just about cover the family food demand, buying fertilizer is expensive. Often they use no or too little fertilizer so that insufficient amounts of nutrients are added to the soil, resulting in soil depletion of nutrients, which leads to decreasing yields. Henaou and Baanante (2006) estimate Malian soils to require an addition of 52 kilograms of NPK per ha in order to balance the outflow of those nutrients. They report the average per hectare use of NPK to 11.7 kg (figures based on the 2002-2004 cropping seasons). The households in our sample (in 2010-2011) add on average 15 kg of NPK per ha (10 kg nitrogen, 2 kg phosphorous and 3 kg of potassium).

The EcoSan facilities studied in this project are built in small separate buildings at the household level. They are urine diverting dry toilets (UDDT) that separate the faecal matter from the urine into separate containers. The products are contained and sanitized for some time and then recycled (using, by turns, two separate pits for the faecal matter). The urine is led into a 20-liter plastic container that is replaced when filled. After a month's storage the urine is sanitized and can be used as fertilizer while faeces need to be stored for 6-8 months. Through a program run by the organization CREPA (Centre Régional pour l'Eau Potable et l'Assainissement à faible coût) over 150 EcoSan facilities have been constructed in the municipality Guégnéka,

consisting of the small town of Fana and its surroundings. The facilities were subsidized by CREPA but the selection of households to benefit from the subsidies was made by the households' village councils. Eligibility was conditioned on three criteria: (1) having own land to cultivate; (2) being at least 10 household members; (3) being able to contribute to the construction of the own toilet as well as to others', for a period of six months, in cash or in kind through material or raw labor.<sup>1</sup>

Beneficiary households were instructed in maintenance of the toilet and in proper use of excreta in farming. In particular, the instruction manual (CREPA-Mali, 2009), available in French and in Bambara, provides guidelines on proper usage and cleaning of the toilet, collection and storage of urine and faeces as well as recommendations on application and dosage of the human fertilizer.

The UDDT's were constructed between March 2006 and May 2009, implying that, at the time of household interviews, they had been in place for between 60 and 22 months. Of the 155 toilets, the vast majority (104, or 67 per cent) was constructed in 2007, 18 in 2006, 28 in 2008 and 5 in 2009. Figure 1 shows the temporal distribution of the investments. The fact that we are studying a project that was implemented some years ago has both pros and cons. The obvious disadvantage is that other things may have happened during the post-construction period making potential effects influenced by other factors than the treatment. However, in addition to the fact that the use of EcoSan is to some extent a permanent treatment, an advantage to study a "settled" program is that we may capture more permanent effects of EcoSan rather than potential initial effects that may fade away after some time (cf. the two cases in Banerjee et al., 2007, where initial large program effects vanished over time). Indeed, the fact that five beneficiaries are no longer active in agriculture and that two other households, for unknown

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<sup>1</sup>Since most families in the area are engaged in farming, the first constraint did probably not exclude many households a priori.

reasons, destroyed their toilets may provide some evidence of this.

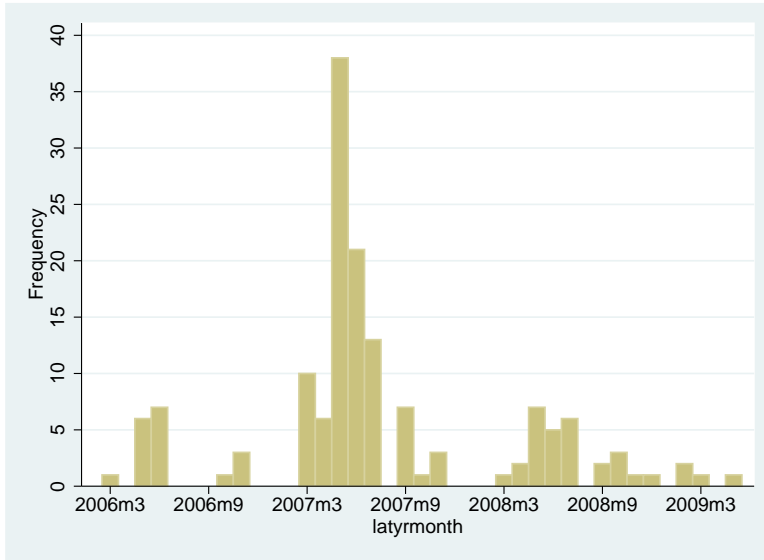


Figure 1: Timing of EcoSan investments

## 4 Data

We face the typical problem of identifying a suitable group of non-EcoSan users to answer the counterfactuals: What would yield per hectare have been had the EcoSan users not used EcoSan? How high would the usage of artificial fertilizer have been had the EcoSan users not used EcoSan? There is no baseline survey performed prior to the introduction of EcoSan facilities, so we need to rely on methods using ex-post construction of the comparison group. Given the non-random placement of EcoSan (that farmers who obtain an UDDT self-select into this treatment) the creation of a control group is a non-trivial task. The problem is arguably aggravated by the time spell between implementation and evaluation. As further described in section 6, we apply a number of alternative (matching) methods and control groups in

order to arrive at a reliable range of estimates of the treatment effects.<sup>2</sup>

Our household data was collected between March 24 and April 24, 2011. The list of beneficiaries includes 180 localities of which 17 are schools, markets and mosques.<sup>3</sup> We were able to interview 155 of the remaining 163 households.<sup>4</sup> Five (urban) beneficiaries were not engaged in farming.<sup>5</sup> These five households were dropped from our data. 40 of the remaining 150 beneficiary households reside in the urban area Fana and 110 live in the surrounding rural villages. Control households were selected in collaboration with CREPA trying to find households meeting the eligibility criteria for a UDDT. We interviewed 97 control households in Fana and 135 households in the surrounding villages. Two rural and one urban household were not active in agriculture and were hence dropped. In addition, we performed 231 inter-

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<sup>2</sup>In our setting, we see three potential sources of bias in the estimated treatment effects: (i) selection on observables, i.e. households that face an EcoSan project have some specific characteristics, making comparisons with other households uninformative in terms of project impact. The remedy is to construct a control group from non-EcoSan households that are similar to the treated households in terms of observables; (ii) contamination of the control group, in our case that village non-participants gain from the existence of the program, implying that the program impact is underestimated. We believe this to be less likely in our setting since treatment concerns a physical investment. This would involve either non-EcoSan users building a toilet outside the program (unlikely) or EcoSan-users giving or trading the own-produced fertilizer to non-EcoSan users. Our questionnaire includes questions of alternative uses of the EcoSan output. We found no evidence of a market for human fertilizers even though the creation of such a market is one explicit goal of CREPA; (iii) selection on unobservables, that is, the extent to which EcoSan users differ from non-users in some "unmeasurable" characteristics. There is clearly an explicit self-selection into treatment where unobserved factors such as ability and effort determine whether a household apply for a toilet or not. The factors determining selection by the village councils probably also include a number of unobservables. We cannot control for such factors. By including control households from another municipality in which CREPA has no engagement of any kind (Kéréla) we believe to somewhat decrease the influence from unobservables.

<sup>3</sup>In all honesty, the list had 184 households, but five households were listed twice and one household was not in the original list.

<sup>4</sup>Of these, two had been destroyed at the time of interview and one was actually never built. We still treat them as treated households (just as we treat as treated the beneficiaries that do not use human excreta as fertilizer).

<sup>5</sup>Four did not own any land and one did not cultivate the 1 ha owned. Their toilets were erected during March-July 2007.

views with (rural) households from another municipality in which CREPA has no engagement of any kind (Kéréla). This gives us 610 interviews in total (150 beneficiaries and 460 controls).

The questionnaire provides data on the amounts of artificial fertilizer used, human fertilizer used, the costs of fertilizer and EcoSan facilities, the area of cultivation, the yields of the cultivation and a number of household indicators. Summary statistics for the groups of treated and controls, as well as for urban and rural households, separately, are found in Table 1.

Table 1: Summary statistics, by treat and by urban-rural

	Treated		Controls		Diff	Urban Mean	Rural Mean	Diff Pval
	Mean	N	Mean	N	Pval			
<b>Yields:</b>								
Tot. (XOF*1000)	947.193	(142)	1086.063	(435)	0.146	683.059	1159.152	0.000
Avg. (XOF*1000)	109.412	(138)	113.918	(434)	0.512	115.614	112.045	0.615
Feedmonth	8.698	(139)	8.637	(449)	0.826	8.322	8.744	0.138
AQ coton	975.508	(57)	1048.725	(222)	0.433	1048.780	1032.354	0.903
AQ millet	793.236	(81)	729.813	(278)	0.424	787.769	732.206	0.491
AQ maize	1216.078	(94)	1024.361	(318)	0.013	1134.440	1049.823	0.283
AQ gr.nuts	879.127	(50)	639.684	(154)	0.023	898.681	670.395	0.099
AQ sorghum	774.592	(123)	749.552	(356)	0.626	856.702	731.390	0.026
<b>Fertilizer used:</b>								
C.coton (50k)	4.000	(146)	4.946	(448)	0.140	2.000	5.482	0.000
C.cereal (50k)	0.834	(145)	0.416	(449)	0.044	1.450	0.255	0.000
Urea (50k)	2.352	(145)	3.448	(449)	0.016	2.008	3.512	0.001
Total (50k)	7.145	(145)	8.819	(448)	0.118	5.458	9.247	0.001
Spent (XOF*1000)	101.359	(131)	107.116	(401)	0.725	55.722	119.026	0.000
<b>H.hold over 7 yrs:</b>								
Size	11.846	(149)	11.316	(456)	0.198	10.963	11.584	0.146
Share 8-15	0.345	(149)	0.334	(456)	0.533	0.322	0.341	0.336
Share 16-54	0.529	(149)	0.567	(456)	0.045	0.581	0.550	0.116
Share 55-	0.125	(149)	0.099	(456)	0.007	0.095	0.109	0.175
Share female	0.438	(149)	0.425	(456)	0.349	0.426	0.429	0.869
<b>H.hold, all:</b>								
Size	14.580	(150)	13.800	(459)	0.073	13.007	14.272	0.005
Share 0-1	0.007	(149)	0.013	(456)	0.083	0.012	0.011	0.800
Share 1-7	0.178	(149)	0.162	(456)	0.200	0.141	0.173	0.018
Share 8-15	0.276	(149)	0.262	(456)	0.293	0.263	0.266	0.801
Share 16-54	0.434	(149)	0.480	(456)	0.019	0.501	0.459	0.041

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	Treated		Controls		Diff	Urban Mean	Rural Mean	Diff Pval
	Mean	N	Mean	N	Pval			
Share 55-	0.098	(149)	0.082	(456)	0.054	0.081	0.087	0.456
Share female	0.459	(150)	0.431	(459)	0.018	0.423	0.442	0.128
Share education	0.439	(150)	0.384	(459)	0.012	0.615	0.336	0.000
Sh. fieldwork	0.459	(150)	0.500	(458)	0.052	0.431	0.507	0.001
Sh. home	0.466	(150)	0.489	(459)	0.478	0.459	0.490	0.334
Sh. oth. inc.	0.143	(150)	0.141	(459)	0.890	0.259	0.108	0.000
<b>H.hold head:</b>								
Female	0.007	(150)	0.002	(459)	0.405	0.015	0.000	0.008
Aged 16-54	0.331	(145)	0.507	(454)	0.000	0.508	0.452	0.257
Aged 55-	0.662	(145)	0.489	(454)	0.000	0.485	0.544	0.231
Education	0.219	(146)	0.179	(452)	0.284	0.561	0.084	0.000
Educ. highest	0.073	(150)	0.074	(459)	0.976	0.141	0.055	0.001
Fieldwork	0.660	(147)	0.681	(455)	0.630	0.549	0.712	0.000
Home	0.565	(147)	0.586	(456)	0.656	0.444	0.619	0.000
Oth. income	0.388	(147)	0.360	(456)	0.539	0.692	0.274	0.000
<b>Size of land:</b>								
Owned (ha)	13.390	(149)	12.946	(454)	0.602	8.700	14.312	0.000
Cultivated (ha)	9.980	(150)	10.621	(457)	0.351	6.563	11.589	0.000
<b>Distance to fields:</b>								
None	0.413	(150)	0.439	(460)	0.580	0.029	0.549	0.000
Less 2 km	0.340	(150)	0.230	(460)	0.008	0.162	0.285	0.004
2-5 km	0.153	(150)	0.157	(460)	0.926	0.456	0.070	0.000
Over 5 km	0.093	(150)	0.174	(460)	0.018	0.353	0.097	0.000
<b>Urban</b>	0.267	(150)	0.209	(460)	0.139	1.000	0.000	.
<b>Assets:</b>								
Asset Index	0.358	(150)	-0.117	(460)	0.017	0.910	-0.261	0.000
Electricity	0.233	(150)	0.205	(459)	0.458	0.881	0.021	0.000
Radio	0.987	(150)	0.941	(459)	0.023	0.993	0.941	0.013
Television	0.467	(150)	0.366	(459)	0.028	0.889	0.249	0.000
Antenna, TV5	0.053	(150)	0.057	(459)	0.878	0.244	0.002	0.000
Parabole	0.073	(150)	0.070	(459)	0.881	0.304	0.004	0.000
Cable tv	0.047	(150)	0.024	(459)	0.155	0.133	0.000	0.000
Fixed phone	0.007	(150)	0.007	(459)	0.986	0.022	0.002	0.011
Mobile phone	0.873	(150)	0.739	(459)	0.001	0.948	0.722	0.000
Refrigerator	0.093	(150)	0.085	(459)	0.753	0.378	0.004	0.000
Gas stove	0.013	(150)	0.035	(459)	0.177	0.133	0.000	0.000
Fireplace	0.680	(150)	0.505	(459)	0.000	0.593	0.536	0.243
Dvd player	0.173	(150)	0.131	(459)	0.194	0.489	0.042	0.000
Air cond.	0.000	(150)	0.002	(459)	0.568	0.007	0.000	0.061
Computer	0.013	(150)	0.011	(459)	0.808	0.052	0.000	0.000
Bike (qty)	2.611	(149)	2.187	(455)	0.012	2.246	2.304	0.741
Moped (qty)	0.912	(148)	0.941	(456)	0.773	1.602	0.745	0.000
Car (qty)	0.060	(149)	0.052	(458)	0.783	0.201	0.013	0.000

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	Treated		Controls		Diff	Urban	Rural	Diff
	Mean	N	Mean	N	Pval	Mean	Mean	Pval
Lorry (qty)	0.020	(149)	0.026	(459)	0.822	0.111	0.000	0.000
Cart (qty)	1.245	(147)	1.039	(456)	0.005	1.045	1.102	0.448
Plough (qty)	2.450	(149)	2.243	(457)	0.204	2.030	2.369	0.043
Horse (qty)	0.034	(149)	0.020	(459)	0.454	0.022	0.023	0.957
Cattle (qty)	2.866	(149)	3.314	(458)	0.488	2.267	3.472	0.071
Pig (qty)	0.013	(149)	0.050	(459)	0.485	0.170	0.004	0.002
Donkey (qty)	1.486	(148)	1.182	(456)	0.011	1.194	1.274	0.517
Sheep (qty)	10.184	(147)	8.244	(438)	0.087	6.338	9.436	0.008
Poultry (qty)	14.932	(132)	9.873	(393)	0.002	11.464	11.045	0.804

In the full sample, the treated group has higher average yields of maize (AQ maize) and groundnuts (AQ gr.nuts) and uses less Urea. Treated households on average are also older (including the age of the household head), more educated and work somewhat less on the fields (Sh. fieldwork). Regarding ownership of durables and household facilities (from electricity to computer, dummies) and other assets and livestock (from bike to poultry, quantity) we note that, when we do observe differences, they are in favor of the treated group. This is also evidenced by the average score of the two groups asset wealth index.<sup>6</sup> As might be expected, urban households have a longer distance to their fields. They are less involved in agriculture, in terms of household members working on the fields, income from other work (Sh. oth. inc.), total yields, use of fertilizer and ownership of agricultural land although their average yields are higher or comparable with rural households. Urban households are also smaller, higher educated, and wealthier.

Table 2 presents some statistics for the sample of beneficiaries. First, note that the rate of compliers is 70 per cent of the designated beneficiaries, i.e. 105 out of 150 households report to have used human fertilizer in agriculture. The average size of land fertilized with human fertilizer is 2 hectares. The vast

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<sup>6</sup>The wealth (or asset ownership) index was constructed following the methodology in Rutstein and Johnson (2004) and Vyas and Kumaranayake (2006). Details are available from the authors on request.



Table 2: Summary statistics, treated sample

	N	mean	sd	min	max
Complier	150	0.700	0.460	0	1
Land cultivated (ha)	150	9.980	7.296	0.0500	40
Land fertilized with HF (ha)	103	2.027	2.984	0.0375	18
HF, on compost	104	0.885	0.321	0	1
HF, directly on land, dry season	104	0.135	0.343	0	1
HF, directly on land, during rains	104	0.250	0.435	0	1
HF, urine only	149	0.315	0.466	0	1
HF, faeces only	149	0.0134	0.115	0	1
HF, urine and faeces	149	0.376	0.486	0	1
Urine, liters applied	46	205.2	227.5	20	1200
Faeces kg applied	6	133.8	82.03	53	280
EcoSan is profitable	132	0.947	0.225	0	1
EcoSan leads to less diarrhoea	127	0.984	0.125	0	1
EcoSan leads to less odor	134	0.821	0.385	0	1
EcoSan leads to more odor	134	0.157	0.365	0	1

majority, almost 90 per cent, applies the fertilizer by putting the sanitized excrements on the compost; a few households (14 percent) use the fertilizer directly on the fields during the dry season and a fourth use the fertilizer directly on fields during the rains. A third of the beneficiaries use urine only, two households report to use only faeces, and around 37 percent uses both urine and faeces. Of the 103 compliers that report to use urine in agriculture, only 46 households have an idea of the quantity applied, reporting an average of 205 liters, and of the 58 household using faeces, only 6 households report the quantity applied, averaging 134 kilograms. Finally, a large majority of beneficiaries report the UDDT to be economically profitable, to have reduced the incidence of diarrhoea, and to have led to less odor.<sup>7</sup>

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<sup>7</sup>We should expect responses to the last questions to be biased. This is evidenced by 125 households reporting the toilet to be economically profitable, which must be considered high given the 105 compliers.

## 5 The quantity and value of human fertilizer used

In order to have an idea of the economic potential of an investment in EcoSan, we need to assess the quantity and quality (nutrient content) of the household production of human fertilizer. Assuming that all excreta are actually taken care of, we may arrive at a theoretical upper bound for the value of human fertilizer (in terms of monetary value or in terms of equivalent artificial fertilizer). Using laboratory data on the nutrient content in samples from the (self-reported) quantity of human fertilizer used in agriculture, we may calculate its actual value. The difference between theoretical and actual values is indicative of potential productivity increases. The estimated values of human fertilizer may also be used to assess the profitability of investment in this type of toilets.

### 5.1 The theoretical value of human fertilizer

There are essentially two methods to arrive at a theoretical estimate of the value of human fertilizer. Jönsson et al. (2004) derive formulas to estimate the intakes of N and P, based on available data on food consumption and protein content from the Food and Agriculture Organization.<sup>8</sup> Using the same data source (FAO, 2011) and method, our estimated quantities of N, P and K per average Malian adult becomes 3.4, 0.5 and 1.7 kilogram per year.<sup>9</sup>

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<sup>8</sup>Based on the correlations between protein intake and the intakes of nitrogen and phosphorus, Jönsson et al. (2004) estimate the volume of N and P to be related to the volume of proteins consumed as (1)  $N = 0.13 * Total\ food\ protein$ ; and (2)  $P = 0.011 * (Total\ food\ protein + vegetal\ food\ protein)$ . Furthermore, they calculate the accumulation of these nutrients in growing bodies to be 2, 6 and 0.6 per cent for N, P and K respectively, among Swedes in the age range 2-17 years.

<sup>9</sup>Our data force us to use the age span 1-15 years instead of 2-17 years for the growing body reductions. We do not include in our calculations children below one year of age. The intake of potassium, K, cannot be estimated in any similar straightforward way since it depends more on specific types of foodstuffs consumed and is not systematically correlated with protein intake. We follow Dagerskog (2007, Table 1), calculating K as 3.339 times

Compared to estimates for five countries presented in Jönsson et al. (2004, Table 3), the average Malian excrete an identical quantity of N, P and K as the average South African. Our estimates are higher than those for Haiti, India and Uganda but lower than the ones for China.<sup>10</sup>

An alternative method is to use data on the nutrient content of urine and faeces, respectively, together with data on the amount of urine and faeces excreted by an average adult. In the guidelines given to the UDDT beneficiaries (CREPA-Mali, 2009), the content in urine (grams per liter) and faeces (grams per kilo) of N, P and K is listed as 5 (33.7), 0.4 (15.4) and 0.3 (22.3).<sup>11</sup> The quantities of urine and faeces excreted vary from person to person and from country to country, depending on climate and diet. In particular, the quantity of urine produced depends partly on the climate as a warm climate may lead to less urine because of more transpiration. Jönsson et al. (2004) reports a default value of urine (faeces) to 1.5 liters per day (30 grams per day) for Swedish adults and 1.6 liters (60 grams) for China. Esray et al. (2001) reports average values (based on Scandinavian studies) of 1.2 liters and 35 gram. We use as an approximation a range of daily excretions between 1.2 to 1.6 liters of urine, and 30 to 60 grams of faeces, per adult and day. This directly yields the total quantity of N, P and K excreted by an average adult Malian to lie in a range of 2.56-3.66, 0.34-0.57 and 1.23-1.80

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the estimated amount of P.

<sup>10</sup>Of interest is whether these nutrients exit the body in form of urine or faeces. This distribution is diet specific since lower digestibility implies that a greater proportion of the nutrients exit the body in the faeces. For many countries data on composition of human excreta is hard to find and we have not been able to find any such information for Mali. Figures in Jönsson et al. (2005, p. 14-15) for Sweden suggest the N, P and K percentage shares in faeces-urine to be 12-88, 36-64, and 27-73, respectively. However, Jönsson et al. (2004) report different distributions from a study on Chinese data.

<sup>11</sup>These figures differ from samples from the CREPA UDDTs in Burkina Faso, reported by Dagerskog (2007, Table 6 and 7) as 5 (20), 0.5 (15), and 2 (15). There is a huge difference in the reported concentration of K in urine. We believe the figure in CREPA-Mali (2009) to be a typo, partly since this concentration gives a very large difference in terms of K between the two methods used, partly because the manual also states that 400 liters of urine contains 0.9 kilos of K, i.e. 2.25 grams per liter. In order to stick to the information in the manual, we chose to use a concentration of 2.25 in our calculations.

kilogram per year. Comparing this with our previous estimate of 3.4, 0.5 and 1.7, both methods gives similar values of all nutrients.<sup>12</sup>

Applying these figures to the average household size and composition in our data, counting the age group 2-15 as half-adults, we arrive at an average yearly production of nutrients of 27-39 kg N (of which 23-31 kg from urine), 3.7-6.1 kg P (of which 1.9-2.5 kg from urine), and 13.2-19.4 kg K (of which 10.6-14.1 kg from urine).<sup>13</sup> Figures are reported in Table 3, columns 3 and 4. This production corresponds to a yearly quantity of 4,700 liters of urine and 118 kilos of dry faeces for the average household. The proportions of nutrients in urine and faeces are important for two reasons. First, it will be informative of the price of not using one form of excreta. Second, during the compost and dehydration process of the faecal matter in the EcoSan toilet, the nitrogen evaporates and can therefore not be reused (hence, only the N in urine is reported in the table). However, it is assumed that phosphorus and potassium are fully recyclable.

In the studied area three different sorts of artificial fertilizer are used, Complexe Coton, Complexe Céréale and Urea. The first two are composites of primarily N, P and K while Urea is very rich in N. The N-P-K percentage concentration of the fertilizers are 14-7.8-15 in Complexe Coton; 15-6.5-12.5 in Complexe Céréale and 46-0-0 in Urea. These fertilizers are bought in sacks of 50 kg. They all had the same price in 2010 and the median reported

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<sup>12</sup>Calculating backwards, the estimates for N, P and K from the first method gives an estimated daily excretion of 1.6, 2.2 and 1.5 liters of urine and 33, 32 and 55 grams of (dry) faeces (dividing the total amount of nutrients consumed/excreted by the per liter/kilo nutrient content).

<sup>13</sup>The size of households is censored at 20 in our data, so this is most likely an underestimation. The quantities of N, P and K from all excreta (urine only) based on the first method and using Swedish shares from footnote 10 become 47 (41), 6.7 (4.3), and 23 (16.8).

Table 3: Theoretical value of human fertilizer

	HH use kg/yr	Avg price EUR/kg	Avg hh prod kg/yr	Urine only kg/yr	Total value EUR/yr	Urine value EUR/yr
N	117	1.1	23.5-31.4	23.5-31.4	25.2-33.6	25.2-33.6
P	21	1.2	3.7-6.1	1.9-2.5	4.3-7.1	2.2-2.9
K	40	1.2	13.2-19.4	10.6-14.1	15.3-22.5	12.3-16.4

*Notes:* Calculations of theoretical value of human fertilizer for an average household in our sample. The average household contains of 6.15 individuals aged 1-15 and 7.67 individuals aged 16 and older. The hh use of NPK reported concerns non-EcoSan beneficiaries.

price paid is 13,400 XOF (around 20 EUR) per sack.<sup>1415</sup> Taking the simple average of nutrient concentration and price, we arrive at an average per kilo price of respective nutrient (column 2 in Table 3) which we use to assess the corresponding value for one year’s production of human fertilizer.<sup>16</sup> The total hypothetical value is calculated to between 4 and 6 EUR per year for an average adult (of which 3.5-5 EUR from urine) implying a total yearly value for the average household of 45-63 EUR (of which 40-53 EUR from urine). Values for respective nutrient are presented in Table 3, columns 5 and 6. These correspond to about 20-30 percent of the households yearly outlays on artificial fertilizer. In volume, the average household’s maximum yearly production corresponds roughly to one sack of Urea and two sacks of Complexe.<sup>17</sup>

It is worth noting that these comparisons are informative of the value of human fertilizer in terms of artificial fertilizers. This should be separated

<sup>14</sup>The exchange rate 1000 XOF = 1.52449 EUR has been fixed since the introduction of the Euro.

<sup>15</sup>Indicating that the median bought fertilizer on credit – a sack from CMDT (the cotton monopoly buyer) in 2010 cost 12,500 in cash and 13,413 on credit.

<sup>16</sup>We do not use the term ”market value”, partly because a market for human fertilizer does not exist, but mainly because the price of artificial fertilizers is subsidized (since 2009). In 2010 and 2011, CMDT bought fertilizer from the company Toguna at prices of 16,500 per sac of Urea and 21,000 per sac of the two Complexe fertilizers.

<sup>17</sup>The average reported use of Complexe Coton, Complexe Céréale and Urea among households *not* using EcoSan is 5, 0.35 and 3.45 sacks per year.

from the need of (human) fertilizers in order to arrive at a (self-) sufficient soil quality. That is, only under the assumption of a correct application of fertilizers can we expect substitution of artificial for human fertilizer to be an optimal strategy.

## 5.2 The value of human fertilizer actually used

The two methods above provide an idea of the economic value of human fertilizer under per-protocol treatment, full reutilization and low nutrient loss. To get an idea of the actual household retention of nutrients in our context, we sampled fertilizers from a selection of toilets in our study and analyzed the nutrient content. Our results suggest the nutrient content in urine (faeces) to be lower (higher) than the values for UDDTs in Burkina Faso as reported by Dagerskog (2007). Our results for urine (6 samples) give a mean value of nitrogen (N) of 2.6 gram per liter (min: 1.9/max: 3.7), which is half the value of the 5 grams reported by Dagerskog. Potassium (K) is also measured to half the Burkinabé value: we measure a content of 1 (0.4/1.6) gram per liter. Our measure of phosphorus (P) is 0.2 grams per liter (0.1/0.3) which amounts to 40 per cent of the content reported by Dagerskog. The content of faeces (3 samples) instead is higher than those in Dagerskog; our mean (min/max) concentration of N, P, and K are, respectively, 27.8 (22.7/30.9); 16.9 (10/22); and 22.5 (14.2/33.2) gram per kilo. Using these means together with the values of daily excretions from above, we arrive at a local theoretical yearly value of human fertilizer of between 2.3 and 3.4 Euro per year for an average adult (1.8 - 2.4 Euro from urine only), which is almost exactly half the values we arrived at in section 5.1.

The value of 2.3 - 3.4 Euros is based on estimated daily excretions. How much human fertilizer is actually used by household farmers in Fana? It appears that not many respondents have a clear idea of the amount of human fertilizer applied on their fields. As we saw in Table 2, out of the 105 compliers, 47 households report to use urine only, 2 households report to use faeces

only, and 56 report to use both urine and faeces. Only three respondents that uses both urine and faeces reported quantities for the two types, using 60 (150), 260 (53), and 400 (70) liters of urine (kg of faeces). Comparing this to the theoretical quantities for these households (that is, using the household composition with the average excretions from above) the retention rate lies in a range of 1 to 7 (20 to 110) percent of urine (faeces) excreted, so there seems to be a potential for increases in the use of human fertilizers, at least for urine. The quantities applied on fields translate to an average of 0.6 kilo N; 1.6 kilo P and 2.3 kilo K per year. This corresponds to less than half a sack of Complex Cérééal in terms of P and K and no practical addition what so ever of nitrogen. Of the households reporting to use urine only, we have information on the quantity for 21 households, applying a mean quantity of 110 liters per year, ranging from 30 to 300 liters. This implies an average retention rate of a bit over 2 percent, ranging from 0.2 to 9 percent. The average quantity of nutrients retained may then be calculated to 0.3 kilo N, 0.02 kilo P and 0.1 kilo K per year. However, since the fertilizer is in general put or poured on the compost before taken to the fields, we may expect most of the nitrogen to evaporate.

As noted in section 4, only 45 percent of the households reporting to use urine also reported on quantity applied, and for those using faeces, the response rate is only ten percent. We do not know whether reporting households are representative for the full sample of compliers. Looking at the number of households that report to use both fertilizers but provide quantities for only one type, retention rates are in general higher, amounting to an average of 0.8 kilo N, 0.05 kilo P and 0.3 kilo K for those (22 households) reporting on urine only and 3 kilos of P and 4 kilos of K for those (3 households) only reporting on faeces. This suggests a substantial input of P and K from faeces though a low reutilization of urine.

Roughly summarizing the above, we find that complying households retain around 2 per cent of the total excretions, the retention rate being high in

Table 4: Condition of toilets as of March-May, 2010

Assessed status of toilet:	Non-complier	Complier	All treated
Good	5	16	21
Passable	14	47	61
Passable-Bad	0	1	1
Bad	24	38	62
Unknown	2	3	5
Total	45	105	150

*Source:* CREPA-Mali (2010)

faeces and low in urine (which has some logic to it, given the easiness to urinate elsewhere). Furthermore, the laboratory data from our samples indicate a nutrient content about half the reported levels in earlier studies. We therefore find a retention rate of nutrients at around one percent of the theoretical quantities of N, P and K. Given these findings, while a concentrated use of human fertilizer may have an effect on the yields of specific crops, we do not expect any economic significant effects from the use of human fertilizer in our sample.

The possibility of using human fertilizer in agriculture clearly depends on how the UDDT is being maintained. Table 4 presents the assessment by CREPA-Mali (2010) of the conditions of the toilets during March-May 2010. While the conditions can be improved quite easy, it is still indicative of how the toilets in general were maintained during the "collection part" of our period of study. That around 40 percent of the toilets was deemed to be in a bad state (even among compliers) decrease our expectations of finding any treatment effects.

### 5.3 Household economic incentives for investment in EcoSan

The construction of the UDDT's in this program was mainly realized through the majority of households contributing with their own labor while CREPA



was covering the expenses for material. Are there any economic incentives for a household to build a UDDT without subsidies?

According to CREPA, the lowest cost of material for this type of toilet is around 190 Euro, using local material. The yearly value of 2.3 - 3.4 Euro per adult estimated in the previous section translates to between 24 and 37 Euro for the average household. This was a theoretical estimate under the assumption that the household retained all excrements. Our data on actual use of human fertilizer suggest the gain to be only a tiny fraction of this sum. This leads us to conclude that the pure economic gain from privately investing in a UDDT is probably negative. Obviously, the economic gains from human fertilizer are far from the only benefits associated with sanitary solutions. Those gains, mainly health gains such as lower incidence of diarrhoea and the like, are however not confined to EcoSan. Similarly, other forms of sanitary solutions will also have a construction cost associated with them while not providing any potential economic upside in terms of reutilization of nutrients. From this perspective, human fertilizer can be seen as an additional gain from choosing ecological sanitation over existing alternatives. This also means, however, that if an appropriate sanitary solution is already in place, a shift to ecological sanitation is quite unlikely.

## **6 Estimating the effect of EcoSan: Empirical setup**

Our interest lies in estimating whether treated households did improve their performance in one of more dimensions (such as average yields or in terms of reduced expenses on artificial fertilizers). As such we are interested in the treatment effect of the treated, i.e. how did treated households perform in comparison to a situation in which they would not have had any UDDT installed (with the latter counterfactual unobserved). However, of perhaps even greater interest is the effect on farming among those that actually used

human excrements as fertilizers. In our sample of 150 EcoSan users, only 105 households report to have used excreta as fertilizer the prior season, that is, a compliance rate of 70 per cent. In addition, 10 households from the control group (all residing in villages where EcoSan exist) report to have used human fertilizer in farming, indicating some "contamination" of the control group.

In a first round of estimations, we compare the potential outcomes  $Y_i(EcoSan)$  and  $Y_i(NotEcoSan)$  where  $Y_i(EcoSan)$  is the outcome of a household having a UDDT and  $Y_i(NotEcoSan)$  is the outcome of the same household not having a toilet. We are interested in the effect

$$E[Y_i(EcoSan) - Y_i(NotEcoSan)|EcoSan],$$

i.e. the difference between the observed outcome of a household having a UDDT and the missing counterfactual, i.e. the potential outcome for the same household had it not had any UDDT, for which we use the outcome of matched controls.

Knowing that we have a number of no-compliers, that is, a number of households that are not using the output from the UDDT in farming, what we are estimating are the average intention to treat (AIT). While this does not provide an estimation of the effect from the use of human fertilizer in agriculture, this effect is still policy relevant, since the main influence of an implementing organization lies in determining whether or not to assign a facility to a household and not in the actual use of the toilet (even though information and education may greatly affect the intended use and as such decrease the difference between the AIT and the ATT). In order to properly estimate the counterfactual, we need to make three assumptions: (i) a household's effect of EcoSan is independent of other's ownership of EcoSan, and households not having EcoSan are unaffected by the program. This is the Stable Unit Treatment Value Assumption, SUTVA (that treatment outcome is unrelated to other's treatment status); (ii) conditional on the covariates  $X$ , the potential outcomes  $(Y_i(EcoSan), Y_i(NotEcoSan))$  are independent of the availability of the program. This is the Conditional Independence As-

sumption, CIA; (iii) the distribution of conditioning variables between the treated and control group is overlapping, i.e. we are assuming the existence of a region of common support. Under these assumptions, the expected outcome for EcoSan users had they not been EcoSan users is the same as the expected outcome for households not being offered an EcoSan facility, i.e.  $E[Y_i(NotEcoSan)|EcoSan, X = x] = E[Y_i(NotEcoSan)|NotEcoSan, X = x]$ .

We are however even more interested in the effect on various outcomes for the households that actually did use the facility as intended, i.e. the average treatment effect on the treated, ATT. In other words, what we want to estimate is the effect of households that are using human fertilizer from an EcoSan toilet in agriculture compared to the counterfactual outcome of the same household not having EcoSan but, being equal, would-be complier,  $E[Y_i(EcoSan, Use) - Y_i(NotEcoSan, Use)|EcoSan, Use]$ .<sup>18</sup>

Assuming that the use of human fertilizer is random, given the conditioning variables  $X$ , we can proceed with matching in a similar way as when estimating the AIT. The Conditional Independence Assumption, CIA, now implies that, given  $X$ , compliance (the use of HF) does not depend of potential outcomes, i.e. whether a household complies or not is independent on  $Y_i(EcoSan, Use)$ ,  $Y_i(NotEcoSan, NotUse)$ ,  $Y_i(NotEcoSan, Use)$ . Under these assumptions, the expected outcome for EcoSan compliers had they not been EcoSan users is the same as the expected outcome for households not being offered an EcoSan facility, complying or not, i.e.

$$E[Y_i(NotEcoSan, Use)|EcoSan, Use, X = x] = E[Y_i|EcoSan, NotUse, X = x] = E[Y_i|NotEcoSan, NotUse, X = x].$$

Hence, one potential counterfactual is to compare compliers with the control group in order to estimate the ATT. We may use all available controls (except the 10 always-takers) in urban and rural Guégnéka as well as the

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<sup>18</sup>Angelucci and Attanasio (2006) provides a discussion of estimation of ATT when assignment is non-random.

separate control group in Kéréla. However, the existence of spillovers (evidenced by the 10 always-takers) may suggest that a better choice is to use as controls the households in Kéréla only (see Behrman et al., 2011b, for a similar approach). This however comes at the cost of excluding the urban dwellings among the compliers.

Another potential counterfactual is to use the non-compliers among the EcoSan beneficiaries in order to estimate the ATT ( $E[Y_i|EcoSan, Use, X = x] - E[Y_i|EcoSan, NotUse, X = x]$ ). This would leave us with 105 compliers and a control group of 45 defiers. This small sample size makes us disinclined to perform matching on this sample. However, disregarding unobservables, households within this group of treated individuals are presumably quite similar in meeting the eligibility criteria (they were, after all, all assigned a UDDT), so in order to compare compliers with eligible controls with the same probability of participating in the program, we may estimate the propensity scores on complying and non-complying treated households only and then impute the probability of compliance on the controls (see e.g. Behrman et al., 2011a, for an example of this approach). We do this as a robustness check to our results.

Do we believe that the assumptions necessary for the estimations above hold? No, in various degrees. In order for conditional independence to hold, we should include all variables affecting compliance as well as outcome. Given that both treatment and selection in our setting are choice variables, and the plausibility that unobservables have affected both administrative assignments to treatment as well as compliance, we do not really think that we are exhausting the set of relevant variables in our specifications. While the effect of unobservables (and spillovers) is presumably smaller when using the remote (Kéréla) control group, that group may differ systematically in a number of observable dimensions that we fail to control for. In order to somehow provide a plausible range of estimates, we therefore apply a quite large number of estimates, both in terms of matching estimators and in terms of subsamples

used.

## 6.1 Outcomes of interest

We use as outcomes a number of indicators that we think are all plausible measures of the effect of treatment. To assess the effect on yields, which we expect to increase if human fertilizer is used complementary to artificial fertilizers, we use as outcome the average (local) market value of yield per hectare, calculated as the total market value of each household's harvest divided by the total area of cultivated land. We also use the number of months the respondent claim that the household can feed itself with the harvest as well as the average yields of specific crops, in quantity per hectare.<sup>19</sup> If human fertilizer simply replaces artificial fertilizers, we do not expect to find any substantial effect for the previous listed outcomes. To assess the extent of substitution, we also use as outcomes five measures on the amount of chemical fertilizer utilized: the per hectare outlays on fertilizers, the total per hectare quantity of fertilizer used, and the per hectare quantity of each of the three fertilizers used.<sup>20</sup>

## 6.2 Balancing the data

As shown in the summary statistics (Table 1), there are systematic differences in a number of covariates between the group of beneficiaries and the control group. We attempt to balance these groups using the propensity scores from a logit model of the probability to obtain a toilet.<sup>21</sup>

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<sup>19</sup>We only consider the "most popular" crops, that is, cotton (244 controls/65 treated), maize (394/114), sorghum (409/136), millet (326/94) and groundnuts (204/60).

<sup>20</sup>We make no attempt to, and with our data cannot, measure the health effects of EcoSan. It is plausible that adequate sanitation positively affects the productivity of farmers due to health improvements. Such health effects are however unlikely to be confined to individual farmers and their families but to have effect at the village level. Estimated effects on productivity are thus additional to the common effects from improved health.

<sup>21</sup>The seminal work on PSM was done primarily by Paul R. Rosenbaum and Donald B. Rubin in the 1970's and 1980's. Two overviews often referred to are Dehejia and Wahba

Selection into the program was made based on three eligibility criteria: (1) having own land to cultivate; (2) being at least 10 household members; (3) being able to contribute to the construction of the own toilet as well as to others', for a period of six months, in cash or in kind through material or raw labor. Our selection of households for the control group was, in a weak fashion, based on the first two criteria.<sup>22</sup> Hence, we do not expect them to differ dramatically between groups, although we did not know the size of possessed land or the exact size of the households prior to interviews.

We expect these eligibility criteria to also affect (at least some of) the outcome variables. This makes them good candidates for inclusion in estimation of the propensity score. Which covariates to include, and how to assert that the resulting sample post matching is balanced, has been much debated though no consensus has emerged ("the literature has not been very helpful", in the words of Imbens and Wooldridge, 2009, page 50).<sup>23</sup> An approach summarized by Stuart (2010) is to "be liberal in terms of including variables that may be associated with assignment and/or the outcomes" (p. 5). One should hence opt for including all variables that are associated with both assignment to treatment and outcome (avoiding omitted variable bias) as well as including covariates that are associated with the outcome but not with assignment to treatment (gives more precise estimates) while including covariates that are associated with treatment assignment only seems less important (may lead to less precise estimates). However, using Monte Carlo experiments as well as real data, Clarke et al. (2011) find that such over-adjustment may result in increased instead of decreased confounding bias.

Our data consist of ex post household characteristics (remember that the

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(2002) and Todd (2008).

<sup>22</sup>I.e., since we started with the "treated" group we did choose our controls based on these characteristics in order to make the control group as similar as possible to the treatment group. Therefore, we did not consider to modeling the selection process explicitly.

<sup>23</sup>For example, as argued in a short and vigorous note (Fu and Li, 2008), blindly trying to maximize the predictive power of the model estimating the propensity score seems like a bad idea since this would decrease the probability of a common support.

toilets had been around for between 2-5 years at the time of data collection). Since we have data for one point in time only, we face the risk, in particular when treatment is successful, that the outcome variable of interest has affected a number of potentially important covariates. If a successful use of human fertilizer implies increased yields, or lower expenditure on artificial fertilizer, a household may contemplate changing their fertility, schooling, or labor supply decisions, increase their ownership of durables, increase (or decrease) the use of fertilizer or change the composition of crops.<sup>24</sup> Of our potential candidates, we therefore decided to include in our logit model a set of covariates that we believe are not likely to suffer from endogeneity: Household size, counting household members older than 7 years of age; the share of age groups and the share of females in that household definition; a dummy for Fana (urban); a dummy for whether the household head is in the age group 55 and older; the education of the household head; the size of owned arable land, and distance to fields (three indicator variables). Table 5 presents the differences in covariates between the group of treated and the resulting group of controls when re-sampling is made by one-to-one matching (upper panel) and five to one nearest neighbor matching (lower panel). We note that, post-matching, no covariate differs between treatment and control at any conventional level of significance.

As a robustness check, we re-estimated the propensity score by including in our logit model all covariates that differed significantly between the treated and the control groups (in a t-test using ten percent as a, liberal, level of significance) as well as a number of covariates that we hypothesize are correlated with the outcome of interest: household size; the share of the household being between 16-54 years of age; the household share of females;

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<sup>24</sup>However, whether assets are increased in response to increased income will depend on the extent to which farmers interpret the income increase as permanent or transitory, the latter will likely have a smaller impact on asset ownership. Note the discussion in Filmer and Pritchett (2001), about the wealth index not mirroring income.

Table 5: Summary statistics, after matching

	One-to-one matching				
	meanT	meanC	diff	s.e.	Pval
H.hold size over 7yrs	11.765	11.985	0.220	(0.536)	0.681
Share female	0.441	0.441	-0.000	(0.018)	0.997
Share aged 16-54 yrs	0.537	0.546	0.009	(0.024)	0.699
Share aged 55- yrs	0.126	0.127	0.002	(0.012)	0.898
H.hold head aged 55-	0.662	0.644	-0.017	(0.058)	0.768
H.hold head has education	0.209	0.207	-0.002	(0.050)	0.975
Urban (Fana)	0.241	0.270	0.029	(0.053)	0.581
Land owned (ha)	13.697	13.474	-0.223	(1.181)	0.850
Distance fields >0-2 km	0.336	0.350	0.015	(0.058)	0.800
Distance fields 2-5 km	0.146	0.139	-0.007	(0.042)	0.863
Distance fields over 5 km	0.080	0.080	0.000	(0.033)	1.000
N	137	137			
	Five-to-one nearest neighbour matching				
	meanT	meanC	diff	s.e.	Pval
H.hold size over 7yrs	11.765	11.749	-0.016	(0.459)	0.973
Share female	0.441	0.436	-0.005	(0.014)	0.746
Share aged 16-54 yrs	0.537	0.556	0.019	(0.020)	0.345
Share aged 55- yrs	0.126	0.118	-0.008	(0.011)	0.441
H.hold head aged 55-	0.662	0.607	-0.055	(0.050)	0.275
H.hold head has education	0.209	0.199	-0.010	(0.042)	0.806
Urban (Fana)	0.241	0.226	-0.015	(0.043)	0.728
Land owned (ha)	13.697	13.311	-0.386	(0.945)	0.683
Distance fields >0-2 km	0.336	0.284	-0.052	(0.047)	0.271
Distance fields 2-5 km	0.146	0.152	0.006	(0.037)	0.878
Distance fields over 5 km	0.080	0.119	0.039	(0.032)	0.220
N	137	310			

*Notes:* Equality of covariates after the estimation of propensity scores using the listed covariates and after re-sampling using average yields as the outcome in two matching estimations: one-to-one matching with no replacement ("M1to1NR") in the upper panel and five-to-one nearest neighbor matching ("M5to1CR") in the lower panel. See text for details.



the household share having any education; the household share working in the fields during the rains; the wealth index; the amount of artificial fertilizers used;<sup>25</sup> the number of crops cultivated; a dummy for Fana (urban); a dummy for whether the household has a compost or not; whether the household has tapped water or not; dummy for whether the household head is in the age group 55 and older; and dummies for whether the household grows millet, maize, haricots or cotton. We re-ran all regressions that follow without finding any substantial differences in results (results available upon request).

Apart from the decision of which covariates to include in the estimation of propensity score, one additional question is which statistic to use as the propensity score. While any monotone transformation is valid, the two main candidates are the estimated probability of treatment (used, for example, by Dehejia and Wahba, 2002) and the linear prediction (i.e. the log odds, or the logit, used, for example, by Rosenbaum and Rubin, 1985). Figure 2 graphs the propensity scores using, in turn, log odds and probabilities. The graph suggests that, regardless of propensity score used, there is a sufficient overlap in scores in order to focus our analysis on the common support. In the following, we use the linear prediction.<sup>26</sup>

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<sup>25</sup>When we use the amount of artificial fertilizers as an outcome, we re-estimate the propensity score without these variables.

<sup>26</sup>We have run the majority of specifications that follows using probabilities instead of logits without obtaining any larger difference in results.

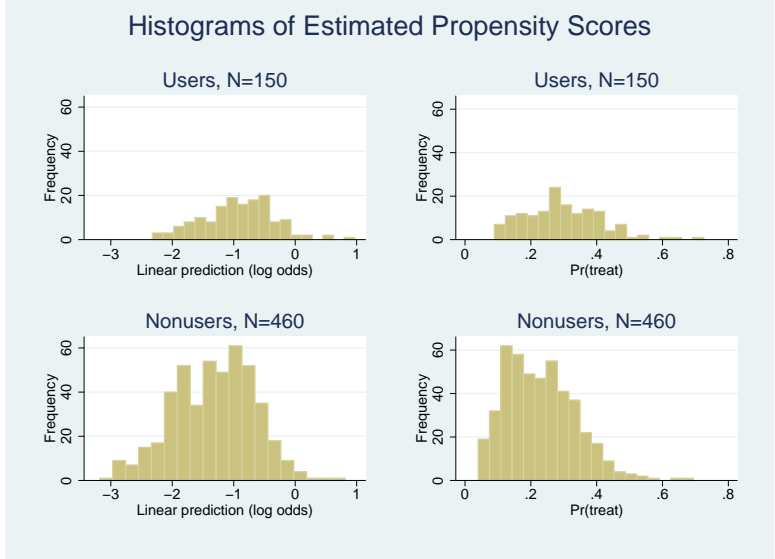


Figure 2: Distribution of estimated propensity scores.

## 7 Estimating the AIT

Our findings from estimation using as treatment group the full sample of beneficiaries are presented in Table 6. To estimate the treatment effect, we apply a number of alternative matching estimators. The first column ("TTEST") gives the raw difference in mean between the full samples of treated and control households and indicates whether the means are significantly different from each other in a t-test. The second column ("OLS") presents the coefficient for a treatment dummy in an OLS regression including as controls the same covariates used in estimation of the propensity scores (listed in section 6.2). Columns 3 to 7 presents the treatment effect from five different matching estimators using the propensity score for balancing. These, in turn, are: one-to-one matching without replacement (column 3, "M1to1NR"); one nearest neighbor caliper matching (with replacement) using a caliper width of 0.25 times the standard deviation of the propensity score (column 4, "M1to1CR"), five nearest neighbor caliper matching

(with replacement) using a caliper width of 0.25 times the standard deviation of the propensity score (column 5, "M5to1CR"); kernel matching using the epanechnikov kernel (column 6, "Kernel") and local linear regression using the tricube kernel (column 7, "LLR").<sup>27</sup> All matching estimators use the common support only. Standard errors in columns 3 to 7 are bootstrapped using 50 replications.

Table 6: Treatment effects, full sample (AIT)

	TTEST	OLS	M1to1NR	M1to1CR	M5to1CR	Kernel	LLR
Avg. yields	-4506	-2114	43.07	-3446	-1858	-1519	-1874
Std.error	6872	6781	8760	10256	8405	8585	8343
N treat/ctrl	138/434	138/434	137/137	137/101	137/301	134/405	137/101
Feedmonth	0.0609	0.0387	0.290	0.384	-0.0383	-0.111	-0.0135
Std.error	0.278	0.276	0.386	0.492	0.354	0.303	0.304
N treat/ctrl	139/449	139/449	138/138	138/101	138/299	135/415	138/101
AQ cotton	-73.22	-95.73	-165.6	-148.3	-15.71	-57.06	-58.30
Std.error	93.34	89.73	99.55	133.5	112.5	107.3	107.2
N treat/ctrl	57/222	57/222	56/56	56/43	56/139	56/177	56/43
AQ millet	63.42	67.12	118.6	138.3	85.46	71.29	64.16
Std.error	79.20	82.44	122.7	102.4	107.7	119.7	117.8
N treat/ctrl	81/278	81/278	80/80	80/61	80/176	79/245	80/61
AQ maize	191.7**	212.5***	201.1**	263.5**	218.1**	212.3**	214.6**
Std.error	76.70	79.54	83.91	121.8	105.5	106.7	103.9
N treat/ctrl	94/318	94/318	93/93	93/72	93/227	90/295	93/72
AQ gr.nuts	239.4**	214.8**	173.2	164.4	195.5	196.2	211.6
Std.error	104.5	106.0	150.4	215.0	172.8	158.0	161.3
N treat/ctrl	50/154	50/154	49/49	49/43	49/115	49/135	49/43
AQ sorghum	25.04	20.99	32.31	55.72	29.82	26.03	19.09
Std.error	51.33	51.71	68.86	81.53	59.91	60.13	58.78
N treat/ctrl	123/356	123/356	122/122	122/92	122/263	119/333	122/92
Art.fert. (exp/ha)	-674.6	-1527	-2140	-1582	-2126	-2260	-1680

*Continued on next page...*

<sup>27</sup>All estimations were made in Stata 12.1, using the package psmatch2.

	TTEST	OLS	M1to1NR	M1to1CR	M5to1CR	Kernel	LLR
Std.error	1191	1202	1737	2058	1455	1748	1592
N treat/ctrl	131/401	131/401	130/130	130/98	130/280	128/373	130/98
Art.fert. (k/ha)	-4.256	-7.392**	-9.903*	-9.647*	-9.245*	-9.121**	-7.972**
Std.error	3.790	3.748	5.628	5.248	4.818	4.274	4.052
N treat/ctrl	145/448	145/448	144/144	144/106	144/314	141/415	144/106
C.coton (k/ha)	-2.140	-2.914	-3.925	-3.376	-3.463	-4.162*	-2.970
Std.error	2.103	2.091	3.176	3.791	3.040	2.466	2.307
N treat/ctrl	146/448	146/448	145/145	145/106	145/314	142/415	145/106
C.cerea (k/ha)	1.356	-0.126	-0.145	-0.489	-0.682	-0.0280	-0.367
Std.error	1.498	1.446	1.870	2.436	1.685	1.918	1.284
N treat/ctrl	145/449	145/449	144/144	144/106	144/315	141/416	144/106
Urea (k/ha)	-3.376*	-4.247**	-5.771**	-5.933**	-5.032**	-4.802**	-4.497**
Std.error	1.749	1.769	2.490	2.885	2.188	2.012	2.021
N treat/ctrl	145/449	145/449	144/144	144/106	144/315	141/416	144/106

Notes: See text

We focus our discussion on the consistency of the estimated treatment effects over column 3 to 7. First, we note that our overall measure of economic gains, the market value of per-hectare average yields (*Avg.yields*) never turns out significant and the estimated treatment effect is, if anything, negative. The same absence of results is found for the self-reported number of months that the household is able to feed itself with the season's harvest (*Feedmonth*). Turning to the yields of specific crops, our results are, in general, far from significant. One crop, cotton (*AQ cotton*), get a negative estimate throughout all columns whereas millet (*AQ millet*), maize (*AQ maize*), groundnuts (*AQ gr.nuts*) and sorghum (*AQ sorghum*) suggest the effect to be positive. Only maize, however, enters at any conventional level of significance, suggesting that the treated group (the 94 treated households growing maize) face average yields about 200 kilograms per hectare and annum over the average yields for control households. Our interpretation is that we find few signs of positive effects on agricultural yields from the event of belonging to the group of

designated EcoSan beneficiaries.

Turning to the use of fertilizers, results are somewhat less ambiguous. We use two aggregate measures for the use of artificial fertilizer; the self-reported total expenditure on fertilizers during last season divided by the reported number of hectares cultivated (*Art.fert.(exp/ha)*) and the aggregate number of kilos of artificial fertilizer per hectare applied on the fields the last season (*Art.fert.(k/ha)*, that is, the sum of Complexe Coton, Complexe Céréale, and Urea). Outlays on artificial fertilizers seems to be somewhat lower among the treated group, although estimates are never statistically significant.<sup>28</sup> The estimates for *Art.fert.(k/ha)* suggest that beneficiaries used on average about nine kilos per hectare less of artificial fertilizer during the season as compared to the control group.<sup>29</sup> Looking at the specific types of fertilizer, the main reduction seems to be in the nitrogen rich fertilizer Urea, which is the only of the three fertilizers whose estimated effect is statistically significant.<sup>30</sup>

In sum, our findings suggest that yields are largely unaffected by the state of being EcoSan beneficiary, although we find support for increased returns on maize. Beneficiary households however seem to use significantly less artificial fertilizers.

## 8 Estimating the ATT

One problem that we have not addressed so far is the presence of non-compliers. In our data, of the 150 EcoSan beneficiaries, only 105 households (76 of 110 in rural Guégnéka and 29 of 40 in urban Guégnéka) reported to use the excrements as fertilizer in farming. This amounts to 30 per cent non-compliance. One could contemplate estimating the local average treatment

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<sup>28</sup>Note that the response rate on this question is lower than for the other indicators.

<sup>29</sup>This translates to about 2 sacks of 50 kilos for the average household.

<sup>30</sup>The estimates for Complexe Céréale are economically and statistically negligible, reflecting that this fertilizer is scarcely used in our sample, the average being half a sack per household.

effect (LATE) using beneficiary status as an instrument for using human fertilizer in agriculture, but since program assignment was not random, we opt for the method described below. We also observe spillovers. Ten non-beneficiary households in Guégnéka (of which 9 in urban Fana) report to use human fertilizer in agriculture.

We proceed as follows. In a first round of estimations, we simply drop the non-compliers (that is, the 45 "defiers"/non-using beneficiaries and the 10 "always-takers"/non-beneficiary users). Under the (strong) assumption that compliers are randomly assigned conditional on the covariates estimating the propensity scores, we then redo our matching exercise, that is, we estimate the propensity score using the compliers and the control group (in the spirit of Behrman et al., 2011b). Our sample then consists of 105 treated/complying households and 450 controls. Results are presented in Table 7 and are largely in line with those found when estimating the intention to treat.

Table 7: Treatment effects, compliers only (ATT)

	TTEST	OLS	M1to1NR	M1to1CR	M5to1CR	Kernel	LLR
Avg. yields	6391	7644	2972	3503	10085	7172	6410
Std.error	7796	7620	12619	11271	8507	8985	9146
N treat/ctrl	97/425	97/425	96/96	96/82	96/255	96/395	96/82
Feedmonth	0.488	0.409	0.479	0.106	0.454	0.295	0.487
Std.error	0.316	0.311	0.400	0.574	0.489	0.313	0.329
N treat/ctrl	95/440	95/440	94/94	94/80	94/262	94/402	94/80
AQ cotton	-59.69	-93.05	-125.3	-96.85	-72.37	-129.6	-90.83
Std.error	106.9	101.3	140.8	166.7	118.0	111.5	127.5
N treat/ctrl	42/219	42/219	42/42	42/37	42/138	40/191	42/37
AQ millet	119.3	111.5	203.1	202.1	123.2	135.3	127.1
Std.error	87.86	90.85	168.4	172.8	139.0	150.1	152.0
N treat/ctrl	60/269	60/269	59/59	59/52	59/158	59/230	59/52
AQ maize	313.8***	326.2***	327.3***	295.7**	354.5***	312.3***	315.3***
Std.error	82.81	85.57	111.0	138.6	106.7	120.7	119.6
N treat/ctrl	69/314	69/314	68/68	68/59	68/200	67/287	68/59

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	TTEST	OLS	M1to1NR	M1to1CR	M5to1CR	Kernel	LLR
AQ gr.nuts	332.3***	288.1**	369.7**	365.1*	272.2	283.8*	288.3**
Std.error	118.0	118.8	175.8	222.2	213.8	147.6	140.9
N treat/ctrl	38/153	38/153	37/37	37/31	37/99	37/132	37/31
AQ sorghum	81.69	63.78	16.54	15.31	45.11	66.16	53.11
Std.error	59.34	59.10	71.01	102.3	80.74	64.89	62.57
N treat/ctrl	87/349	87/349	86/86	86/71	86/222	86/326	86/71
Art.fert (exp/ha)	-233.1	-1171	-2062	-3208	-1337	-1971	-1833
Std.error	1392	1395	2366	2182	2099	1958	1839
N treat/ctrl	91/393	91/393	90/90	90/72	90/235	88/361	90/72
Art.fert. (k/ha)	-2.247	-6.537	-8.608	-11.73*	-6.751	-7.409	-7.519
Std.error	4.441	4.352	5.597	6.923	5.441	5.674	5.656
N treat/ctrl	100/439	100/439	99/99	99/82	99/269	99/402	99/82
C.coton (k/ha)	-0.512	-1.701	-1.617	-3.081	-1.298	-1.523	-1.449
Std.error	2.468	2.428	3.491	4.219	3.223	3.597	3.446
N treat/ctrl	101/439	101/439	100/100	100/83	100/269	100/402	100/83
C.cereia (k/ha)	1.510	-0.344	-1.200	-2.595	-0.114	-0.716	-0.994
Std.error	1.725	1.652	3.442	3.470	1.804	2.093	2.259
N treat/ctrl	100/440	100/440	99/99	99/82	99/268	99/403	99/82
Urea (k/ha)	-3.142	-4.390**	-5.589**	-6.174**	-5.119**	-5.055*	-4.960**
Std.error	2.052	2.061	2.568	3.043	2.392	2.672	2.456
N treat/ctrl	100/440	100/440	99/99	99/82	99/268	99/403	99/82

Notes: See text

The estimated effect on maize yields is larger than in Table 6 but we find no effect on average yields, suggesting either that the market value of the increase in maize yields is insufficient to influence average yields or that the increase in maize is counteracted by decreased yields of other crops (we find no support for this latter hypothesis). We also find some indication for the yield of groundnuts to be larger for compliers, but this estimated effect does not appear robust to the use of different matching estimators. The estimates regarding the use of artificial fertilizers are however less significant, in

particular for the total sacks used, *Art.fert.(k/ha)*. The finding that treated households use around five to six kilos less of Urea per hectare and annum seems however to be supported when analyzing the impact on compliers only.

In a second round of estimations, we use as controls only the group from Kéréla, which is presumably a group that was least (totally un-) affected by the EcoSan project. In this case we dropped the 29 compliers living in Fana since Kéréla do not have any urban area, leaving us with a sample of 76 treated/complying households and 231 controls.

Results are presented in the upper panel of Table 8. The difference in yields of maize is estimated to be much larger, and the effect on the use of Urea is lower and insignificant or weakly significant.<sup>31</sup>

In the lower part of Table 8, we rerun the two rounds of estimations (for the full sample and for rural households only), but we now estimate the propensity score from a (logit) regression on the treated sample only, that is, using compliers as the positive outcome and non-complying EcoSan beneficiaries as controls. We then impute the propensity score for the control group that we are using (i.e. all controls minus the always-takers in the first round, the control group in Kéréla in the second round). This is similar to Behrman et al. (2011a). The estimated effect for the yield of maize seems very robust to these changes. However, the effect on the use of Urea is lower and generally insignificant when using imputed propensity scores on the full sample but similar in magnitude, and at least weakly significant, when using imputed propensity scores for the rural households only. Overall, we infer that these results do not change our conclusions from Table 7.

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<sup>31</sup>To economize on space, only the variables found to have an impact in the previous table are shown. Results for the other treatment effects are available upon request.



Table 8: ATT, other samples and propensity scores

	TTEST	OLS	M1to1NR	M1to1CR	M5to1CR	Kernel	LLR
Rural households only							
AQ maize	267.1**	336.9***	514.6***	528.6***	406.4***	412.5***	396.8***
Std.error	103.1	108.9	147.2	184.6	145.6	150.4	138.7
N treat/ctrl	50/167	50/167	48/48	47/33	47/104	45/124	48/34
Urea (k/ha)	-5.254**	-5.164**	-5.223**	-3.852	-3.926	-4.113	-4.546*
Std.error	2.154	2.252	2.462	3.485	2.418	2.727	2.678
N treat/ctrl	74/225	74/225	72/72	72/53	72/139	72/169	72/53
Table 7, imputed propensity scores							
AQ maize	313.8***	326.2***	309.8***	288.5*	302.4***	292.8***	292.4***
Std.error	82.81	85.57	103.0	151.8	111.3	98.52	95.82
N treat/ctrl	69/314	69/314	67/67	67/57	67/193	67/311	67/57
Urea (k/ha)	-3.142	-4.390**	-5.338*	-3.407	-2.201	-2.304	-2.743
Std.error	2.052	2.061	3.032	2.928	2.107	2.105	2.129
N treat/ctrl	100/440	100/440	100/100	100/82	100/285	99/432	100/82
Rural households only, imputed propensity scores							
AQ maize	267.1**	336.9***	338.4***	301.4*	305.5**	365.2***	301.7**
Std.error	103.1	108.9	127.8	168.3	120.8	118.6	128.5
N treat/ctrl	50/167	50/167	49/49	48/40	48/121	45/113	49/41
Urea (k/ha)	-5.254**	-5.164**	-6.475**	-6.470*	-6.354**	-5.116*	-6.117**
Std.error	2.154	2.252	3.037	3.921	2.576	2.746	2.651
N treat/ctrl	74/225	74/225	72/72	71/57	71/158	67/159	72/58

Notes: See text

## 9 Conclusions

In large parts of the world, the lack of proper sanitation entails disastrous health effects which to a large extent could be prevented by available, context adapted, sanitation facilities. Bad sanitation is also wasteful. Human excrements contain the most important nutrients necessary for plants to grow and tend to end up in rivers, leading to eutrophication, instead of being used

productively.

This paper analyzes the potential economic household gains from ecological sanitation, a sanitary solution that permits the recycling of nutrients as fertilizer. For farming households, the use of human fertilizer may imply either a decrease in the use of artificial fertilizers (improving the household's economy through lower expenditures) or an increase in the total amount of fertilizer (improving soil quality and hence increasing agricultural yields).

We study a project in Mali where we collected demographic, economic and farming data from 618 households, of which 155 benefitted from the construction of a type of urine separating dry toilet. We also measured the nutrient content of human fertilizer in a selected sample of beneficiaries. Together with results from previous studies on the relation between protein intake and nutrient content, we calculate the potential value of human fertilizer by the average household in our sample to around 30 per cent of the use of artificial fertilizer. The actual retention of human fertilizer is however found to be a small fraction of its potential.

Applying (propensity score) matching methods, we analyze the effect on a number of outcome variables ranging from the value of average crop yields and yields of specific crops to the use of artificial fertilizer. We find that the use of human fertilizer have no effect on household wide agricultural productivity, though it seems to increase the yields of maize. Our results also suggest that households with ecological sanitation substitute artificial fertilizer with human fertilizer at 10 to 15 per cent of the average household use of artificial fertilizers, despite the indication of a much lower level of nutrients recycled.

While our results indicate that the household economic gain from the use of ecological sanitation may be somewhat limited, implying small economic household incentives for investing in such solutions, we do not account for health effects at the household or community level. However, the relevant comparison when contemplating the construction of ecological toilets is not

the status quo of inadequate latrines or open defecation but rather other sanitary solutions. The scope for ecological sanitation will hence be larger when there are no other forms of sanitation already in place.

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