Comparing soil nutrient depletion in typical urban, peri-urban and rural farming systems in Ghana

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Abstract
In a response to rapid urban growth in Africa, specialized urban and peri-urban vegetable production systems emerge and contribute significantly to urban food security. These production systems are dominated by smallholders and can achieve despite poor soils astonishing high profits. This, however, require intensive fertilization (e.g. 100-200 t/ha poultry manure) and year-round irrigation of 600-1600 mm, which adds further nutrients but also contributes to nutrient leaching. In this highly dynamic input-output system fanners are demonstrating that „permanent" cropping is possible on poor tropical soils but for the price of high N and K losses and water eutrophication. The situation is described for the case of lettuce, cabbage and spring onion farming in and around Kumasi, Ghana. Nutrient balances and depletion costs have also been calculated for the more conventional (rural) maize-cassava intercrop for comparison as well as rainfed tomato farming. From fanners point of view, the „costs" of nutrient mining vary with the availability of farm land. In the conventional system, fanner still can to shift when soil fertility is low, thus pay only for the preparation of a new field. In the land constrained urban vegetable system the costs of nutrient mining can best be assessed through their replacement costs via poultry manure or mineral fertilizer. Additional off-site costs of the vegetable system might be balanced through the fertilizer value of the water (for irrigation) and appears in general marginal in comparison with water pollution through the urban run-off.

Key **words:** *nutrient depletion, vegetable farming, urhan agriculture, environmental pollution*

INTRODUCTION

Soil nutrient depletion is one of the most serious forms of land degradation in large parts of Africa where negative soil nutrient balances are a predominant feature (Stoorvogel and Smaling, 1990, Smaling, 1998). Exceptions are compound farms, backyards or systems with external input, e.g. manure derived from off-farm grazing (Vlaming et al., 1997; Smaling and Braun, 1996). This paper has its focus on input intensive urban and pen-urban agriculture, which appear as response to rapid urban growth in large parts of Africa. These permanent farming systems are specialized on perishable crops, such as vegetables and can contribute significantly to urban food security. As nutrient balance data from such systems are hardly to find (Van den Bosch et al., 2001), this paper tries to compare nutrient depletion and its costs for the farmer in three selected urban, peri-urban and rural farming systems. It also tries to outline off-site effects on environment and health on the case of Kumasi, Ghana

MATERIALS AND METHODS

Data on urban, peri-urban, and rural farming systems and their nutrient management (fertilization, residue management, etc.) were obtained through farm surveys addressing in total 238 farms around Kumasi and 100 open-space and backyard farms in urban Kumasi. The information obtained (yields, inputs used, etc.) was translated into nutrient in- and outputs in kg per hectare and year using nutrient content data from standard literature (cf. Annex I). Data on erosion. nutrients in rainwater etc. were obtained From expert consultation, local

literature and laboratory analysis. Data on nutrient leaching were estimated as 20% of applied potassium, which is a compromise between the transfer function given by Stoorvogel and Smaling (1990) and the results of Poss et al. (1997). For nitrogen leaching we applied the transfer function of Stoorvogel and Smaling (1990). For irrigated urban vegetable production we estimated the leaching/runoff figures through the comparison of laboratory data of farm and control plots under consideration of all other nutrient in- and outputs. Nutrient content of imgation water was analysed in the laboratory by standard methods and compared with data provided by Cornish et al. (1999). Data on soil nutrient pools in pen-urban Kumasi were taken from Quansah (2000) and IBSRAM/KNUST (unpubl.). Data on nutrients in ash from different 2-4 years old fallows were taken from Van Reuler and Janssen (1993) and Anthofer and Kroschel (2001). Nutrient recovery in ash was assumed as 5-7% of N, 64-73% of P, 38-42% of K in fallow biomass following the same authors. The assessment of the fallow contribution and leaching losses would require more sophisticated field studies than it was possible so far.
The **costs** of nutrient depletion were estimated using the replacement cost approach (Drechsel and Gyiele, 1999) and the land rental a farmer would have to pay to acquire (shifting cultivation) a new plot in rural and peri-urban areas (cf. Annex 1).

RESULTS

Among the various field types identified in and around Kumasi (Table **1)** we focussed in this report on the following three:

- Intensive **urban** open-space mixed vegetable production (year round irrigated with drain water)
- Intensive **peri-urban** tomato production (rainfed)
- Traditional **rural** cassava-maize production (for comparison)

1. Traditional maize-cassava farming in rural and pen-urban Kumasi

Less than **10%** of the farmers use mineral fertilizers and if then only at a modest rate. Only a small minority of the farmers applies (poultry) manure. The nitrogen losses through harvest are not compensated for by these low nutrient inputs or through slash and burn, neither in an assumed low fertility/productivity nor a normal fertility/productivity scenario (Table 2). This exploitation of the soil nutrient pool requires to shifting cultivation. Ash depletion accompanied by the infestation of weeds is the main reason for abandoning a field after cassava harvest, and to open another field. As even the N input of a 20-yr fallow would not be sufficient to supply sufficient nitrogen (Van Reuler and Janssen, 1993) the incorporation of Mucuna for N-fixation might be an interesting option to balance the N outputs (Anthofer and Kroschel, 2001). It is interesting to note that not the low inherent soil P pool but nitrogen appears to be the limiting factor.
In view of cost assessments, it would be inappropriate to use the replacement cost approach to assess the costs of nutrient depletion as long as shifting cultivation is practised. The rental **of** a new plot is about 10-50 USD/ha depending among others on its proximity to the city. Clearing (slash and bum) would costs additional 40 USD/ha but this cost factor might be accommodated in the farming budget.
A survey carried out by NRI and partners around Kumasi did not reveal a connection between land price (value) and presumed soil fertility (Adam, 2001, pers. communication). However, Nunan et al. (2000; p. 87) reported that land rental might differ according to soil quality. This might become more significant as fallow periods for soil regeneration are declining in the peri-urban area

2. Rainfed tomato production in wider peri-urban Kumasi

Akumadan is a production area in the vicinity of Kumasi specialised on tomato farming. The data show that farmers use mineral fertilizer in excess of crop demand resulting in all scenarios we calculated in positive soil N, P, and K balances (Table 2). This confirms earlier results reported by Quansah (2000). To verify this assessment it would be necessary to get field data on nutrient losses through run-off However. it appears that this system does not produce on-site costs of nutrient mining but might cause off-site effects due to (ground- and stream-) water eutrophication (Kyei-Baffour and Mensah. 1993). On the other hand, irrigated farming downstream of this area might benefit from the increased nutrient load.

Table 1: Characteristics of common crop fanning systems in urban (UA) and pen-urban (PUA) Kumasi (IBSRAM/IWMI, unpubl.)

Farm hpe (number interviewed)	Cropping seasons per year	Area	Residues left	Average fallow periods	NPK use (% of farms)	Am. Sulphate use (%)	Average N-P-K amount kg/ha/yr	Poultry manure (use % of farms)	PM rate (kg/ha/yr)	Irrigation
Maize mono (26)	1-2	**PUA**	89%	3 yrs	15-30	0	18-18-18	8	350	no
Maize/Cassava (56)	1	**PUA/RA**	64%	3-5 yrs	9	2	14-9-9	2	440	no
Mixed farming (55)	1	**PUA/RA**	67%	5-8 yrs	4	0	3-3-3	4	36	no
Tomato (53)	3-4 (4th imgated)	**PUA**	95%	1-4 yrs	100	40	up to 90-38-38 (per season)	34	963	Some in dry season
D n season vegetables (18)*	3	**PUA**	98%	4-6 yrs	90		162-96-96	25	582	Yes in dry season
Mixed farming with cocoa/oilpalm (30)	1	**RA**	79%	13-20 yrs	0	0	0	0	0	no
Vegetables (all seasons) (40) **	3-11	**UA**	25%	0	5	3	2700-1800-1350	100	50,000 – 150,000	yes
Maize mono (40)	1	**UA**	75%	0.5 yr	3	0	18-18-18	15	204	no
Urban backyard (20) (+840 via city survey)	1-2	**UA**	13-40%	nil	17%	0	0	23	50	55%

Nutrient data in N. P_2O_5 and K_2O

UA: urban agriculture, PUA: peri-urban agriculture, RU: rural agriculture

* Okra, tomato, garden egg, cabbage, others, partly in rotation

** Spring onions, lettuce, cabbage, others (farm size: 0.05-0.36 ha, bed size: 18-36 m2, no. of beds: 26-120; frequency lettuce 9-11 seasons/yr, cabbage 2-3 seasons/yr, spring onions 8-9 seasons/yr)

Table **2:** Nutrient balance calculations (kg/ha/yr) for three farming systems

Tomato, rainfed, peri-urban

	High input				Low input		
	N	P205	K2O		N	P205	K20
Harvest (3 x)	-43	-11	-75	(2 x)	-26	-6	-46
Residues	0	0	0		0	0	0
Irrigation	0	0	0		0	0	0
Rain	6	4	8		6	**4**	8
Erosion	-6	-2	**-4**		*-6*	-2	-4
NPK	270	113	113		89	37	37
Manure	9	6	4		0	0	0
Leachinglrunoff	-81	-4	-23		-29	0	-7
Sum	***155***	***106***	**23**		***34***	33	***-12***

Maize/Cassava, rainfed. rural

	Normal productivity				Low productivity			
	N	P205	K2O		N	P2O5	K2O	
Ash input	15	23	114	(4-yr-fallow)	6	24	72	(2-yr-fallow
Harvest	-58	-27	-67		-27	-13	-31	
Residues	-18	-10	-19		-9	-5	-10	
Irrigation	0	0	0		0	0	0	
Rain	6	4	8		6	4	8	
Erosion	**-4**	-2	-4		-3	-1	-2	
NPK	14	9	9		0	0	*0*	
Manure	0	0	0		0	0	0	
Leaching	-13	0	-23		-7	0	-14	
Sum	***-58***	**-3**	18		**-34**	**9**	**23**	

Vegetables, irrigated, urban agriculture

	N	P2O5	K2O
Harvest	-1050	-255	-825
Residues	-225	-225	-225
Irrigation	15	9	65
Rain	6	4	8
Erosion	-6	-2	-4
Manure/NPK	2700	1800	1350
Leachinglrunoff	-1616	-20	-411
Sum	-1*76*	1311	**-42**
Measured (field-fallow)	-225	1719	-54

Available soil nutrient stocks (kg/ha/20cm) in **low** lands

	N (labile)	P205	K2O
Low end	*625*	*38*	*940*
High end	1785	127	7900

3. Mixed vegetable production (irrigated urban agriculture)

This is a very in- and output intensive farming system as the nutrient flows show (Table **2). Poultry** manure **(PM)** application rates are high as many soils are sandy and frequent irrigation is leaching the applied nutrients (Table **3). PM** is applied over the year at a rate of 50t/ha on cabbage and 150 t/ha on lettuce and spring onions (range 100 – **240** t/ha). For **NPK** mostly a 15-15-15 blend was used, partly supplemented by Ammonium Sulphate. In general, urban farmers rely only on poultry manure except for cabbage which receives a certain amount of **NPK** while peri-urban vegetable farmers use low amounts of industrial fertilizer and add poultry manure **as** a supplement.

Table 3: Nutrient a lication throu h fertilizer and manure

		Lettuce/s r.onions	Avera e rotation/
	1350 + 580		
P205	900 + 580		
K2O	650 + 580	1950	1350
Source	PM + NPK	PM	

Another nutrient source is irrigation water (Table 4) which contains especially downstream of the city significant amounts of nitrogen. In our calculations we used moderate (upstream) nutrient contents.

Nutrient input through wet and dry deposition, on the other hand, is modest: 6 kg N, 4 kg P205 and 8 kg K2O (Anthofer and Kroschel, 2001).

Tab. 4: Nutrient application (kg/ha/yr) with irrigation water in and around Kumasi (calculated from own data and Cornish et al., 1999).

Application range:
640 – 1600 mm/yr (l/m2); average: 1050 mm or 70 cans/m2/yr (one can = 15 litre)

Calculation based on 1000 mm/yr

N	10-15 kg N/ha upstream Kumasi and 100-150 kg N/ha downstream from Kumasi
P	7-11 (- 700) kg P_2O_5 depending on time (7-11 =normal range; 700+ kg in a few weeks after start of rains, still to be confirmed; no location difference up- vs. downstream)
K	50-80 kg K_2O depending on the stream and amount irrigated

Nutrient losses through erosion are relatively small in this bed and furrow system but leaching rates are high due to the sandy soil texture.

The high number of growing periods over the year and related high frequency of harvests is also significantly contributing to nutrient losses. Lettuce can be cultivated 9-11 times/yr, cabbage 2-3 times/yr, and spring onions 8-9 times/yr. As only 25% of all farmers interviewed leave vegetable residues on their fields another significant amount of nutrients, is lost with the residues (Table 2). In summary, the nutrient balances of easily leached N and **K** are negative while (non-leachable) phosphates accumulate in the topsoil. Irrigation downstream of the city could improve the negative N balance, however, not balance it. Only better residue management could turn the nepative N and K balances of this system into positive ones.

Nutrient losses, however, concern leached N and K as well as accumulated (wasted) P. These costs account for 10 USD per ha and year if replaced with poultry manure (only N and K) or 79 USD if also P is considered.

Water pollutioti

In input intensive (peri)urban farming, the high load of nutrients can be washed into streams or the shallow ground water and – as stated earlier on - contribute to water eutrophication (Kyei-Baffour and Mensah, 1993). The nutrients might re-enter the system by providing a significant contribution to the nutrient requirements of irrigated crops. This is consistent with interviews held with farmers who believed the water provided a detectable fertilizer benefit to their crops (Cornish et al., 1999). Thus off-site costs due to water eutrophication might be balanced for by the fertilizer value of the water.

Besides nutrients, shallow wells and stream recorded a high number of faecal coliforms and pesticide residues. Although in this case the source might be farm-made (spraying and application of fresh poultry manure) it Corms only part of the general urban sanitation problem and general high water pollution (Drechsel et al., 2000, Mensah et al.. 2001).

CONCLUSION

In the rural-urban continuum, nutrient balance assessments confirm that the traditional rural staple crop production system is based on ash (and soil) nutrient depletion which the farmer is trying to counteract through continuous shifting cultivation. In intensive rainfed tomato production, on the other hand, farmers are apparently using too high fertilizer rates which results in generally positive nutrient balances (or over-fertilisation). Even more dramatic is the situation in irrigated urban vegetable farming. Here the dilemma of the urban farmers derives from the limited farming space in the urban context without options for shifting cultivation. Their output oriented cash crop production thus depends on high chemical inputs *to* cope with low native soil fertility. Farmers are in a vicious cycle demanding again and again high rates of nutrients which they are leaching through high irrigation rates. At the end of the year, their systems show P accumulation and N and K mining. Offsite effects on water quality are likely through runoff and leaching of nutrients but more harm will derive from E. coli and pesticide contamination of water bodies (Drechsel et al., 2000).

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Nutrient content in harvested products and residues (kg/ton harvested product), and in poultry manure and NPK (%)).

	N	P2O5	K2O
Cassava	3-4	1-2	5-7
Cassava residues	2-6	1-3	2-3
Maize	14-15	6-9	4-5
Maize residues	6-11	4-7	18-24
Lettuce	*3-4*	*0.7-1*	*2.5-3*
Cabbage	*3-4*	*0.7*	*2.5-3*
Onions	*3*	*0.9-1.2*	*2-3*
Vegetable residues	1	I	1
Tomato	1.5-2.5	0.3-0.7	3.2-3.8
Tomato residues	1.4	0.7	1.2
Poultry manure	2.2-3.2	1.1-2.5	0.8-1.8 %
NPK	15	15	15 %

Ref: Diverse sources and lab analyses by IBSRAM/IWMI.

Typical yield ranges found on-farm in the Ashanti region

Maize	(0.8) 1.4-1.8 t/ha/yr
Cassava	(4.5) 9.0-11.0 t/ha/yr
Tomatoes	18-27 t/ha/yr (three seasons per year)
Vegetables	7.0-9.0 t/ha/yr (rainfed)
Vegetables	300 t/ha (irrigated)
	30-38 kg lettuce/m2/yr (8-11 lettuce seasons/yr)
	24-36 kg cabbage (2-3 seasons per year)
	26-35 kg spring onions (6-10 seasons per year)

Ref IBSRAM/IWMI data

Cost factors (all in USD)

Farmland rental (for cropping and fuelwood)	
Around Kumasi	10-50 USD/ha/yr
Akumadan area (tomato production)	30-40 USD/ha/yr
Clearing (labour)	40 USD/ha
Building plot price	10000-12000 USD/ha
Replacement costs (mineral fertilizer)	USD 0.5/kg N. 1.22/kg P_2O_5, 0.43/kg K_2O
Replacement costs (poultry manure)	USD 0.035/kg N, 0.053/kg P_2O_5, 0.074/kg K20

Ref: Nunan et al. (2000): IWMI data