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ENVIRONMENTAL SYSTEM ANALYSIS OF TOMATO PRODUCTION IN GHANA

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ABSTRACT

Tomato *(Lycoperscicum lycopersicum)* production in Ghana is characterised by low yields and high fertiliser input. This is compounded in the long run by production shocks due to environmental pressures such as drought, pests and diseases. Tomatoes among other vegetables are more susceptible to these biotic constraints than other crops. Chemical pesticides and, to a limited extent, integrated pest management practices have been applied to control the pests and diseases but with limited success. Pesticides use has been ineffective, leading farmers to apply high dosages. The aim of this study was to identify the most important sources of greenhouse gases, acidifying and eutrophying compounds associated with tomato production in Ghana and identify options to reduce the environmental impacts. Life Cycle Analysis (LCA) methodology was used in the analysis (Cradle to gate approach). The inventory analysis involved collection of data on raw material, energy consumption and emissions. From the results, it was revealed that approximately 8,544 kg CO_2-equivalents of greenhouse gas was emitted per hectare of tomato production in Ghana. Among the three main components of greenhouse gases, CO_2, CH_4 and N_2O, N_2O accounted for the highest value followed by CO_2. When we considered the activities that generated greenhouse gases, fertiliser application ranks the first with a share of 97%. The total hectare acidifying emissions from SO_2 and NO_X were calculated to be 19.50 kg SO_2 –equivalent. When we considered the result in terms of actual and SO_2 equivalent, emission of NO_X was larger than that of SO_2. About 211.50 kg PO_4 equivalent of eutrophying compounds was found to be discharged per hectares. With regards to options to reduce environmental impact of tomato production in Ghana, practices that recover investment cost and generate a profit in the short term are preferred over practices that require a long term to recover investment costs: practices that have a high probability associated with expected profits are desired over practices that have less certainty about their returns.

Key Words: Acidification, eutrophication, greenhouse gases, *Lycoperscicum lycopersicum*

RÉSUMÉ

La production de la tomate *(Lycoperscicum lycopersicum)* au Ghana est caractérisée par de bas rendements et une utilisation élevée de fertilisants. Ceci résulte à la longue en une perte de productions, par suite des pressions environnementales à savoir la sécheresse, les pestes et maladies. Parmi d'autres légumes, les tomates sont plus susceptibles à ces contraintes biotiques que d'autres cultures. Les pesticides chimiques, et, dans certaines limites, la gestion des pratiques intégrées de la peste a été appliqué pour contrôler les pestes et maladies mais avec un success limité. L'utilisation des pesticides a été inefficace, poussant les fermiers à appliquer de fortes doses. L'objectif de cette étude était d'identifier les sources les plus importantes de gaz à effets de serre,des composés acidifiants et eutrophiants associés à la production de la tomate au Ghana et identifier les options pour réduire les impacts environnementaux. La méthode d'analyse du cycle de vie (LCA) était utilisée dans l'analyse (*Cradle to gate approach*). L'analyse de l' inventaire concernait la collecte des données sur le matériel brut, la consummation et l'émission de l' énergie. De ces résultats, il était révélé qu'approximativement 8,544 kg CO_2-equivalents de gaz à effets de serre était émis par hectare de production de tomate au Ghana. Parmi les trois principaux composants de gaz à effet de serre, CO_2, CH_4 et N_2O, le gaz N_2O présentait de valeurs les plus élevées suivi par le CO_2. En considérant les activités générées par les gaz à effet de serre, l'application des fertilisants se range le premier avec une part de 97%. Le total des émissions acidifiantes par hectare issue de SO_2 et NO_X étaient évalué à 19.50 kg SO_2 –equivalent. En considérant le résultat en terme d'actuel et equivalent SO_2, l'émission de NO_X était plus large que celle de SO_2. Environ 211.50 kg PO_4 equivalent de composés eutrophiants étaient émis par hectare. Pour ce qui est des options visant à réduire l'impact environnemental de la production de tomate au Ghana, les pratiques recouvrant le coût d'investissement et générant un profit à court terme sont plus préférées que les pratiques où le recouvrement coût d'investissement est à long terme: les pratiques à profitabilité élevée, associées aux profits attendus sont les mieux désirés que les pratiques avec bénéfice incertain.

Mots Clés: l'acidification, de l'eutrophisation**,** gaz à effet de serre, *Lycoperscicum lycopersicum*

INTRODUCTION

Tomato production in Ghana covers about 37,000 hectares and is characterised by high inputs of fertilisers and chemical biocides which contribute to several environmental burdens (Penning and Conrad, 2007; Zou *et al.*, 2007; Daker *et al.*, 2008; Tao *et al.*, 2008). These environmental burdens can be reduced through technical options of the production activities. Therefore, analysing the environmental performance of tomato production provides an effective first step to develop, implement and improve its environmental management in Ghana.

The environmental impact of the tomato production in the tropics, especially in sub Saharan Africa (SSA), has not received much attention from the research community. Without action on the part of the tropical tomato production interests, this disparity is likely to increase. If capacities are not built in SSA to develop local familiarity and competence in Life Cycle Analysis (LCA) techniques, tropical tomato production risks being inadequately represented in the international market. To date, there have not been extensive studies on the environmental performance of tomato production in Ghana. The overall objective of this study was to identify technical options to reduce the environmental impact of tomato production in Ghana.

MATERIALS AND METHODS

System boundary. This study was carried out in accordance with ISO 14044 (2006) that specifies requirements and guidelines for conducting LCA. Figure 1 provides the process flow and system boundaries of tomato production in Ghana. Tono irrigation project in Navrongo in the Kassena-Nankana district of the Upper East Region in Ghana, was used for the study. Tomatoes are produced in all the ten regions of Ghana, covering all the major ecological-climatic zones. Tono irrigation project was chosen because of its unique ecological climatic zone and contributes enormously to tomato production in Ghana. The

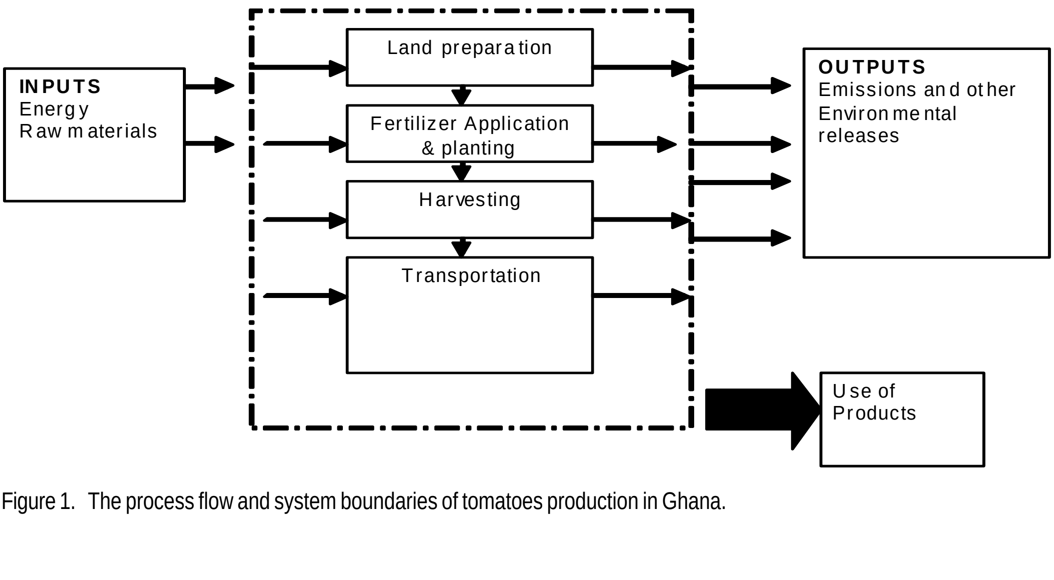

Figure 1. The process flow and system boundaries of tomatoes production in Ghana.

flow chart of a production processes support data collection, and facilitates reporting and transparency of an LCA (SETAC, 1994).

Additional interviews were done to check data quality by understanding which processes the given data specifically cover. In this study, the functional unit used were the mass of 1 kilogramme of tomatoes produced per hectare. The purpose of the functional unit was to provide a reference unit to which the inventory data are normalised.

Emission inventory calculation. Emission inventory data were not available in Ghana. Therefore, all emissions were calculated as a function of production activities and the emission factors using the following Equation (1):

Emission = Activity × Emission Factor ………………….................. .... Equation (1)

Activities in production that contributed to the emissions were fertiliser application and fuel usage.

Table 1 shows activity data for calculation of emission originating from activities associated with tomato production in Ghana. The activities in the tomato production include land preparation, fertiliser application, planting, pesticides application, herbicides application, harvesting, and transportation to the mill. Planting, fertiliser application, and harvesting were done manually. When the activities which generate the pollutants could not be quantified, the emission was calculated using the emission factor related to the production capacity (Table 2). In this context, the production capacity was virtually presumed an activity. The emission factor is emission per unit activity for a certain compound which was obtained from references (Table 2).

The results of emission calculations are expressed in kilogrammes of pollutant either emitted or generated from tomato production system per year. The activity data and emission factors that were used to quantify the emissions were considered to be the best data available to-date. The values which were not available were obtained from sources which were commonly used and widely accepted, such as emission factors described by the IPCC (2006). However, some data could not be obtained directly from one source. As such, integrated information from multiple sources was adapted to estimate the values.

Environmental impact. The integrated environmental impact of the emissions was calculated using classification factor as illustrated in Table 3 (Heijungs *et al.*, 1992).

Impact = Emission × Classification Factor …………………................................. Equation (2)

In this analysis, classification factors based on the three environmental categories, namely global warming, acidification and eutrophication, were applied.

RESULTS AND DISCUSSION

Greenhouse gas emission. Approximately 8,544 kg CO_2-equivalents of greenhouse gas was emitted per hectare of tomato produced in Ghana (Table 4). Among the three main components of

TABLE 1. Activity data for the calculation of emissions from irrigated tomatoes production in Ghana

Source	Activity	Quantity (kg ha^{-1})
Land preparation	Diesel use	93.96
Planting	Manual	
Pesticide application	Pesticide use (PROPANIL)	51.52
Fertiliser application	N - Fertiliser use	277.87
	P - Fertiliser use	277.87
	K – Fertiliser use	277.87

greenhouse gases, namely, CO_2, CH_4 and N_2O; N_2O accounted for the highest values; followed by CO_2. Fertiliser application ranked the first among the activities that generate greeenhouse with a share of 97% (Table 4). Nitrous oxide emissions from agricultural soils occur through nitrification and denitrification of nitrogen in soils (Velthof *et al.*, 2002). Nitrous oxide emissions are very dependent on local management practices, fertiliser types, land use and climatic and soil conditions (Jiang and Huang, 2001). According to Feney (1997) and MacKenize *et al.* (1997), soil N_2O emission increases with N fertiliser application. The use of slow and controlled release fertilisers and/or stabilised fertilisers have been successfully used in serveral agro-environmental conditions, particularly in rice (Carreres *et al.*, 2003; Tang *et al.*, 2007) and in agricultural and horticultural crops, especially on sites with a high precipitation rate, intensive irrigation and/or light sandy soils (Pasda *et al.*, 2001). Other studies demonstrated their potential to reduce environmental pollution in regards to N_2O emissions (Delgado and Mosier, 1996; Shoji *et al.*, 2001). Nitrification inhibitors alone in reducing N_2O emissions from several agrosystems (Majumdar *et al.*, 2002; Macadam *et al.*, 2003).

Acidifying emissions. The total hectare acidifying emissions from SO_2 and NO_X were calculated to be 19.05 kg SO_2 –equivalent (Table

TABLE 2. Emission factors used for the calculation of the emission in tomato production irrigated sytems in Ghana

Source	Compound emitted	Emission factor	Unit	Reference
Land preparation	CO_2	3150.00	g kg^{-1} fuel	Schwaiger and Zimmer, 1995
	N_20	0.02	g kg^{-1} fuel	Schwaiger and Zimmer, 1995
	CH_4	6.91	g kg^{-1} fuel	Schwaiger and Zimmer, 1995
	NO_X	50.00	g kg^{-1} fuel	IPCC, 1997
	NMVOC	6.50	g kg^{-1} fuel	IPCC, 1997
	CO	15.00	g kg^{-1} fuel	IPCC, 1997
N-fertiliser use	N_20	0.03	kg N_2O-N kg^{-1} N	IPCC, 1997
	NO_X	0.03	kg N_2O-N kg^{-1} N	IPCC, 1997
	NO_3	0.35	kg N_2O-N kg^{-1} N	IPCC, 1997
P-fertiliser use	PO_4^{-3}	0.20	kg PO_4^{-3}- P kg^{-1} P	IPCC,1997

TABLE 3. Classification factors used in equation (2) for emissions of greenhouse gases and acidifying gases

Environmental impact category	Compounds	Classification factors	Reference
Global warming	CO_2	1 kg = 1CO_2-eq	IPCC, 1997
	CH_4	1 kg = 21CO_2-eq	
	N_2O	1 kg =310CO_2-eq	
Acidification	SO_2	1 kg =1SO_2-eq	Heijungs *et al*., 1992
	NO_X	1 kg =0.71SO_2-eq	
Eutrophication	NO_X	1 kg = 0.13 PO_4-eq	Heijungs *et al*., 1992
	NO_3	1 kg = 0.1 PO_4-eq	
	N	1 kg = 0.42 PO_4-eq	
		1 kg = 1 PO_4-eq	
	PO_4	1 kg = 3.06 PO_4-eq	
	P	1 kg = 0.022 PO_4 -eq	
	COD		

TABLE 4. Greenhouse gases emission from irrigated tomato production in Ghana

Activity/source	CO_2 emission		CH_4 emission		N_2O emission		Total	Percent
	kg ha^{-1}	kg CO_2- eq ha^{-1}	kg ha^{-1}	kg CO_2- eq ha^{-1}	kg ha^{-1}	kg CO_2-eq ha^{-1}	kg CO_2 eq ha^{-1}	
Land preparation	295.97	295.97	0.649	13.635	0.002	0.744	310.35	3
Fertiliser application					26.553	8,234	8234	97
Total	295.97	295.97	0.649	13.635	26.555	8,235	8,544	100
Percent		3.5		2		96		

5). Actual and SO_2 equivalent was less than that of NO_X. Fertiliser application was the major contributors to SO_2 emission due to improper application of fertiliser. Tomato production generates acidifying agents through their production stages. Acidification is measured as the amount of protons released into the terrestrial/ aquatic system. The classification factors of acidification potential (AP) are routinely presented either as moles of H^+ or as kilogrammes of SO_2 equivalent (Heijungs *et al.*, 1992). Deposition of acidifying compounds may lead, in the long term, to losses of soil buffer capacity by loss of cations, lower pH, increased leaching of nitrate accompanied by base cations, increased concentrations of toxic metals (e.g aluminium) and changes in the balance between nitrogen species (Van Breemen *et al.*, 1983). Large scale acidification of soils and water is recognised as an important environmental problems and a potential threat to ecosystems (Rodhe *et al.*, 1988).

Eutrophying emissions. From this study, about 211.50 kg PO_4 equivalent of eutrophying compounds was found to be discharged per hectares (Table 6). When we consider these eutrophying compounds as nutrient potential substances in terms of PO_4 equivalent, PO_4 effluent from fertiliser use in tomato production was the most abundant and this amounted to 177.03 kg PO_4-eq ha^{-1}. Fertiliser use causes problems with water quality when they run into rivers or percolate into groundwater (Indiati and Sharply, 1995). The runoff of nitrate and phosphate into lakes and rivers fertilises them, and causes accelerated eutrophication (Carrizosa *et al.*, 2003).

Eutrophication is a process that occurs during the development of many rivers and represents an increase in primary productivity due to extenal and internal nutrient input (Kirilova *et al.*, 2010). Due to increased human impact during the past century, eutrophication has substantially increased worldwide and has become a key concern for water quality management (Carpenter *et al.*, 1999).

The concentration of nutrients and organic pollutants increased as a consequence of anthropogenic inputs particularly from domestic,

TABLE 5. Acidifying emissions from irrigated tomato production in Ghana

Activity/source	SO_2 emission	NO_X emission	Total	Percent
	kg ha^{-1}	kg SO_2-eq ha^{-1}		
Land preparation	4.70	3.34	3.34	18
Fertiliser application	22.13	15.71	15.71	82
Total	26.83	19.05	19.05	100

TABLE 6. Eutrophying emissions from tomato production in Ghana

Activity/source	Eutrophying emission		Total
	kg ha^{-1}	kg PO_4 eq ha^{-1}	%
Land preparation	4.70	0.610	0
Fertiliser application			
PO_4	177.03	177.03	84
NO_X	22.13	2.88	1
NO_3	309.80	30.98	15
Total	513.66	211.50	100

agricultural and municipal sources. Fianko *et al.* (2010) studied the impact of anthropogenic activities on the fluctuation of nutrients along the Densu River and its tributaries in Ghana, and observed high concentrations of nutrients. The relatively high concentration of nitrate and phosphate in the river indicated that it was quite eutrophic. The ecological and social-economic consequences of the effect of eutrophication on ecosystem functioning and services have been recognised (Kirilova *et al.*, 2010). Consequently, legal and management measures against the negative impacts of nutrient enrichment must be given a policy framework directives in Ghana, particularly Africa.

Options to reduce the environmental impact of tomato production. From the above results, fertiliser application was the highest threat to the environment. Technologies for mitigation of greenhouse gases (GHGs) in agriculture and the potential decreases in emissions of CO_2, CH_4 and N_2O (Table 4) are the equivalents carbon emission reductions for CO_2 and N_2O based on their respective ratios of global warming potential. Of the total possible reduction in radiation forcing CO_2 equivalents, approximately 96% could result from reduction in N_2O emissions.

Estimates of potential reductions ranged widely, reflecting uncertainty in the effectiveness of recommended technologies and the degree of future implementation. To satisfy food requirements and acceptability by farmers, technologies and practices should be sustainable, provide additional benefits to farmers and must receive consumer acceptance (Kendall and Pinentel, 1994). Farmers have no incentive to adopt GHGs mitigation techniques unless they improve profitability. Some technologies, such as no-till agriculture or strategic fertiliser placement and timing, were already being adopted for reasons other than concerns for climate changes. Options for reducing emissions, such as improved farm management and increased efficiency of nitrogen fertiliser use, will maintain or increase agricultural production with positive environmental effects.

These multiple benefits will likely result in high cost effectiveness of available technologies. Practices that recover investment cost and generate a profit in the short term are preferred over practices that require a long term to recover investment costs, i.e., practices that have a high probability associated with expected profits are desired over practices that have less certainty about their returns (Tao *et al.*, 2008). When human resource constraints or knowledge of the practice prevent adoption, public education programmes can improve the knowledge and skills of the work force and managers to help advance adoption (Walker and Schulze, 2007). Comprehensive national research programmes, education and technology transfer will be required to develop and diffuse knowledge of improve technologies.

Tropical conditions in which fresh produce is grown in most developing countries favour production and rapid multiplication of pests and disease and, also make dependence on pesticides imperative. Pesticides used in tomato production in Ghana have been ineffective, leading farmers to apply high dosages. Heavy use of pesticides has been reported in Africa (Mwanthi and Kimani, 1990; Okello and Okello, 2010). Application of pesticides and, to a limited extent integrated pest management practices to control the pests and diseases needs critical consideration to reduce its environmental impacts. Farmers' education and access to information play an important role in the use of alternative pest management practices.

Domestic policies regarding pesticide usage must be regulated based on risks faced by farmers and the selection of the types of pesticides in order to meet pre-harvest interval hence attain residue limits. The overall policy implication of successful control of pesticide use by farmers needs a combination of instruments. Reducing pesticide usage requires farmer training on safe use procedures combined with monitoring and enforcement of safe use practices.

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