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Application of the Von Thünen Model in Determining Optimal Locations to Transport Compost for Crop Production Outside of Yaoundé, Cameroon

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ABSTRACT This research developed and applied a non-linear von Thünen model to explore and determine optimal and profitable distances for transporting compost from the city-centre of Yaoundé, Cameroon to surrounding farm areas. Baseline model results indicate that Yaoundé's annual compost production (124,320 tons) is only profitable for farms located within a 79 km radius of the city. Those farms located within a 79 km (or less) radius of the city can be characterized as "beneficial farming zones"; they enjoy significant profits and have a positive shadow price value from the use of compost. However, farms located within an 80-400 km radius of the city incur losses and a compost shadow price that approaches zero. The losses of the latter farms indicate that it is not profitable to use compost for crop production beyond this radius range. As compost production increases and more of it is made available to farmers, the shadow price of the compost decreases. A lower shadow price translates into higher farm profits because lower costs are incurred for crop fertilization. Farms located at distances of 80 km, 70 km, 60 km, 50 km, and 45 km from the city-centre will attain a zero shadow price when compost availability increases by 25%, 50%, 75%, and 100%, respectively. Therefore, it is recommended that the city of Yaoundé amends its politics to help increase compost shipments to those farmers located farthest from the city-centre, so that these farmers may lower their overhead costs and increase their overall farm profits. Appropriate state actions could include appropriating funds for roads and transportation infrastructure, as well as encouraging the formation of farm cooperatives in order to transport bulk shipments of compost at lower rates.

1. INTRODUCTION

With each Yaoundé resident generating about 0.75 kg/day of household waste, the capital-city of Cameroon produces a daily amount of 1125 t of organic household waste from its 1.5 million inhabitants (Ngnikam 2000). However, because of the poor road infrastructure in most neighbourhoods that limits transportation and garbage collection, only 810 t of daily household waste is currently collected in the city. If all of Yaoundé's collected household waste were to be processed into compost (assuming 1 t household waste creates 0.42 t of compost), it would generate roughly 124,320 t of compost annually (Ndoumbé 1994).

Given that Yaoundé's 6.8% annual population growth rate is accompanied by an increase in per capita food consumption, one can expect to see a higher output of household waste. The rise in household waste should therefore result in a higher quantity of compost generated in the city. The compost could be readily used by local farmers to aid in crop production and fertilization, however the low demand for compost within the urban areas of Yaoundé has raised doubts regarding its profitability, thus resulting in low conversion rates.

Because only small-scale composting activities exist within the peri-urban zones of Yaoundé, distant farmers do not have large quantities of compost at their disposal for crop production. According to the Cameroonian Ministry of Agriculture (2003), the area surrounding Yaoundé (Centre province) accounts for a total of 1000 compost users (representing 32% of fertilizer users) with each of them demanding on average 124.320 t/year of compost. However, this com-

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post demand could be higher if compost price was fixed or subsidized at a level close to the value of chemical fertilizing elements it contains. With a production cost of 21,000 FCFA[1]/t and a market selling price of 30,000 FCFA/t, the compost of Yaoundé is about 3.75 times more expensive than the value of chemical fertilizing elements (nitrogen, phosphorus, and potassium) that it contains. The nutrient content per ton of Yaoundé compost is 8.7 kg nitrogen, 1.7 kg phosphorus and 6 kg potassium. The same nutrients in mineral fertilizer are locally sold respectively at 348, 652 and 652 FCFA/kg, implying that the value of chemical fertilizing elements contained in compost is: $[(8.7^{*}348)+(1.7^{*}652)+(6^{*}652)]=$ 8,048FCFA/t. The discrepancy in prices is often a deciding factor for farmers who must choose between purchasing Yaoundé compost or a substitute fertilizer (Jaza 2005).

Another limiting factor in the distribution and use of compost in the surrounding farm regions is its bulk and weight. Because very large amounts of compost are needed for fertilization, transport costs often prevent shipments from reaching farm areas outside of Yaoundé. The high transport costs make the compost shipments unaffordable for most farmers, a problem which is exacerbated by Yaoundé's inadequate and poorly maintained roads. Distribution becomes an even greater problem the further one travels outside the peri-urban areas, as most distantly located farms are not accessible by vehicles transporting compost. The transport rate for crops and compost in Cameroon is 40 FCFA/t per km, which is too expensive for most farmers (Yecke 1994; Jaza 2005). The effect of transportation costs on the overall compost price significantly decreases farm and business demand for compost.

The distant farms are at greater risk of seeing decreased farm activity as a result of using compost. As rural cooperatives and Non-Governmental Organizations (NGOs) are quick to point out, as long as there are no government subsidies to counteract the transport costs of the compost, farmers will continue to choose mineral fertilizer. Unlike compost, mineral fertilizer is assumed to be less voluminous, which equates to cheaper and easier transportation. This, coupled with the fact that it requires less labour, means that it is more profitable for the farmers to use mineral fertilizer rather than compost (Yecke 1994; Waas et al. 1996; Jaza 2009).

However, labour shortage is not a major problem for compost use for farming activities in Cameroon where the agricultural sector employs 70% of the population (and contributing 30% of the Gross Domestic Product and 60% of exported revenues). Like everywhere in the country, about 60% of the people live in rural areas such as the villages surrounding Yaoundé, with agriculture being their main occupation. These rural inhabitants enjoy working on compost farms to the extent that the unemployment rate, which is 20% in Yaoundé, is only 5% in rural areas (Jaza 2005). In addition, half of the food supply consumed in Yaoundé comes from its surrounding areas and the city counts on the production of its rural compost users to feed its residents (Ministry of Agriculture 2003).

Waste management experts believe that, at its current production and transport costs, the use of compost can still be profitable and that farmers should consider a partial replacement of the mineral fertilizer with compost, especially those farmers located within a certain radius range or distance from the city of Yaoundé (Ndoumbé et al. 1995; Nkamleu 1996; Drechsel and Kunze 2001).

Given the current debate, the most pertinent question is which farm regions would profit the most from using Yaoundé compost, with profit being measured in terms of successful crop production and overall farm profits. In light of this, the main objective of this paper is to analyze and calculate the benefit of using compost on agricultural farms, with the use being a function of the distance from the farm to the city in order to determine the optimal profitable locations. Our study hypothesis assumes that agricultural farms located closer to the city gain more benefit from using compost for crop production than those located farther away.

2. FIELD SURVEY AND DATA COLLECTION

The Cameroon field survey was conducted from August 2007 to February 2008 within the urban and peri-urban areas of the capital city of Yaoundé. Included in the survey were 15 other surrounding villages with similar soil and climatic conditions to each other. All the selected villages surround Yaoundé, forming several rings radiating out from the city-centre.

The city-to-farm distance of 80 km was selected as the primary ring because there are a greater number of farmers (within the 0-80 km area of the city-centre) who actually use Yaoundé generated compost. The distance from one ring to the following ring was 80 km. On this basis, the survey used five rings of 80, 160, 240, 320, and 400 km radius from the city-centre. The rings (also referred to as regions) were categorized according to their distance from the city-centre as follows: *Region 1*: 0-80 km; *Region 2*: 80-160 km; *Region 3*: 160-240 km; *Region 4*: 240-320 km; and *Region 5*: 320-400 km.

Three villages were randomly selected in each region. In each of those villages, nine compost-using farms were chosen, which translated into a combined total of 135 composting farms throughout all of the five regions. The selected agricultural farms were those cultivating the 11 main food crops/vegetables of the survey area, namely: pepper, lettuce, tomatoes, carrots, cabbage, maize, watermelon, onion, okra, green beans and white beans.

Using a prepared questionnaire and interview schedule, cross-sectional primary data of the cropping year 2006/2007 were collected from the selected farmers. The data collected were estimates made from our own assessments of the farm (soil type, annual farm production, overall profits, crop amounts, farmers themselves, etc.). They also included the yield of crops, as well as the intensity of the use of crop-production inputs (compost, mineral fertilizer, animal manure, labour, irrigation, seeds, and pesticides). In order to easily gather the first set of collected data for von Thünen modelling, the Cobb-Douglas production elasticities of the main crops were estimated by using the SPSS software program (see Appendix 1). Those data points were supplemented by the average amount of resource availability (compost, land, labour) per farmer, and other secondary data such as the selling prices of all inputs and crops, and the transport rate of compost and crops (see Appendices 2 to 4).

3. DATA ANALYSIS: THE VON THÜNEN MODEL

In order to analyze and calculate the benefit of providing compost to various agricultural farms surrounding Yaoundé, the distance between the farm in question and the city must be calculated to determine which locations will profit most from compost deliveries. The von Thünen model is preferred because it illustrates the use of distance based-gradient analysis such as the change in value for a variable (for example, farm profit) as a function of the increasing distance from the city-centre.

3.1 Background and Application of the von Thünen Model to our Research Problem

The von Thünen model was developed in 1826 during the age of industrialization by the German landlord von Thünen, who described the land use practices radiating out from a central market location as an "Isolated State". His theory was summarized in the following statement: "*Imagine a very large town, at the centre of a fertile plain which is crossed by no navigable river or canal. Throughout the plain, the soil is capable of cultivation and of the same fertility. Far from the town, the plain turns into uncultivated wilderness which cuts off all communication between this State and the outside world. There are no other towns on the plain. The central town must therefore supply the rural areas with all manufactured products and in return it will obtain all its provisions from the surrounding countryside*" (von Thünen 1826, translated in 1966). Many recent studies (such as Alonso 1964; Sinclair 1967; Beckmann 1972; Bauer and Hummelsheim 1995; Jaza 2005, 2009) in which a city is situated at the centre and where the transportation cost is important in understanding the land use patterns of the surrounding areas, have demonstrated that the von Thünen model approach is still very useful.

In applying the von Thünen model of distance based-gradient analysis, this paper assumes that the compost produced (for example, 124,320 tons/year) from household waste within the city of Yaoundé is to be transported for fertilization purposes to the agricultural farms located within the aforementioned five 'regions'.

It was assumed during this study that all crops were produced in rural areas (that is, Regions 1-5) for the purpose of food consumption in the city. While crops produced from the surrounding farm regions are transported to Yaoundé for this reason, the rural areas in turn receive compost generated from organic household waste in Yaoundé for the purpose of fertilization.

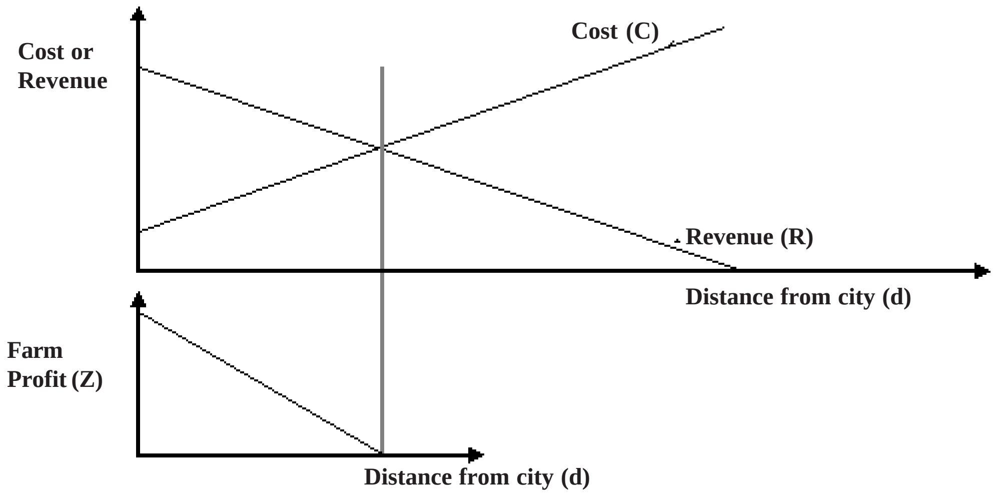

Fig. 1. Farm profit derived from revenue and cost as a function of the distance to the city in the von Thünen model

3.2 Theoretical Computation of Farm Profit in Function of the Distance from City

Since the cost of transporting compost in a given surrounding rural area is directly related to the farm's distance from the city, the total cost (C) of using compost to produce crops in a given rural area will increase with the distance from the city (Fig. 1). Conversely, the revenue (R) gained by producing crops with compost in a given surrounding rural area will decrease as one moves further away from the city (Fig. 1). The difference between revenue (R) and total cost (C) will give the farm profit (Z). The further the farm is located from the city, the less profit it derives from using compost in its crop production. This farm profit decreases to zero up to a certain "cut-off distance" from Yaoundé-city (see Fig. 1).

Based on both the von Thünen model and the applied mathematical formula from Bauer and Hummelsheim (1995) in Figure 1, the farm profit obtained from each crop produced with compost in a rural area located at a particular distance from the city would be equal to the Revenue *minus* Total cost (see Equation 1).

$$Z=R-C \quad (1)$$

The revenue in turn is equal to: the Crop price *times* Crop yield, *times* Cropping area (see Equation 2).

$$R=PYu \quad (2)$$

The total cost from Equation (1) is equal to: the Crop transport cost, *plus* Compost cost, *plus* Compost transport cost, *plus* Other variable costs, *plus* the Cost of seeds and pesticides (see Equation 3).

$$C = O+J+H+V+F \quad (3)$$

Finally, the farm profit can be obtained by subtracting Equation (3) from Equation (2) which is written as: the Revenue *minus* Crop transport cost, *minus* Compost cost, *minus* Compost transport cost, *minus* Other variable costs, *minus* the Cost of seeds and pesticides (see Equation 4).

$$Z = R-O-J-H-V-F \quad (4)$$

Taking into account the revenue expression of Equation (2), the farm profit is equally expressed as follows:

$$Z= PYu-O-J-H-V-F \quad (5)$$

where:

Z: farm profit; **R**: revenue; **C**: total cost; **P**: crop price; **u**: cropping area; **O:** crop transport cost; **J**: compost cost; **H**: compost transport cost; **V**: other variable costs such as animal manure, mineral fertilizer, labour, and irrigation costs; **F**: costs of seeds and pesticides.

Equation (5) is derived according to the von Thünen methodology and represents the farm profit as a function of the distance from the city.

3.3 Analytical Framework and Mathematical Expression of the von Thünen Model

The farm profit of Equation (5) is the linear objective function. A farmer producing crops with compost at a particular rural area maximizes his/her profit subject to the constraints of the non-linear Cobb-Douglas production function and the availabilities of compost, labour and land. Hence, the von Thünen model developed in this study allows for the integration of the estimated Cobb-Douglas production elasticities (Appendix 1) with non-linear programming. Other exogenous variables and parameters from secondary data sources are also entered into the model. Under the assumptions/database of the model (Appendices 1 to 4), the system of equations [Equations (7) through (16)] from the non-linear programming is solved using the GAMS (*General Algebraic Modelling System*) software program in order to determine the main endogenous variables such as: the maximum farm profit, the optimal level of compost use, and the compost shadow price as a function of city-to-farm distance and compost availability.

3.3.1 Mathematical Formulation of the Model

The constructed von Thünen model consists of the objective function and the constraints. The mathematical formulation of the objective function that is to be maximized is:

$$\text{Max } Z = PYu\text{-}O\text{-}J\text{-}H\text{-}V\text{-}F \quad (6)$$

Where:

The crop transport cost **O** is equal to: Crop transport rate *times* City-to-farm distance, *times* Crop yield, *times* Cropping area (see Equation 8). The compost cost **J** is equal to: Compost price *times* Compost intensity, *times* Cropping area (see Equation 9). The compost transport cost **H** is equal to: Compost transport rate *times* City-to-farm distance, *times* Compost intensity, *times* Cropping area (see Equation 10). The cost of any of the variables (except compost) included into the Cobb-Douglas (C.D) function is equal to: its Price *times* Intensity of its use, *times* its Cropping area. **V** represents the total cost of these C.D. variables (except compost), which are: animal manure, mineral fertilizer, labour, and irrigation (see Equation 11). **F** is equal to: the sum of costs (that is, Price *times* Intensity *times* Cropping area) of seeds and pesticides (see Equation 12).

By further developing the objective function equation of expression (6) into details, we obtain:

Objective Function:

$$\text{Max } Z = \Sigma_c P_c Y_c u_c \quad \text{[Crop revenue]} \quad (7)$$
$$- \Sigma_c td Y_c u_c \quad \text{[Crop transport cost]} \quad (8)$$
$$- \Sigma_c P_k K_c u_c \quad \text{[Compost cost]} \quad (9)$$
$$- \Sigma_c tdK_c u_c \quad \text{[Compost transport cost]} \quad (10)$$
$$- \Sigma_c P_c A_c u_c - \Sigma_c P_m M_c u_c - \Sigma_c P_e L_l u_c - \Sigma_c P_w W_c u_c \quad \text{[Cost C.D. variables]} \quad (11)$$
$$- \Sigma_j \Sigma_c P_j I_{j,c} u_c \quad \text{[Cost of seeds and pesticides]} \quad (12)$$

This objective function Max Z is to be maximized according to the constraints of the Cobb-Douglas production function, as well as the availabilities of compost, labour and land. The constraints and availabilities are mathematically formulated in Equations (13) to (16), as shown below:

Constraints:

$$Y - \beta_0 K_c^{\beta 1} A_c^{\beta 2} M_c^{\beta 3} L_c^{\beta 4} W_c^{\beta 5} \quad \text{[Cobb-Douglas production function]} \quad (13)$$
$$\Sigma_c K_c u_c \leq G \quad \text{[Compost availability]} \quad (14)$$
$$\Sigma_c L_c u_c \leq E \quad \text{[Labour availability]} \quad (15)$$
$$\Sigma_c u_c \leq S \quad \text{[Land availability]} \quad (16)$$

where the endogenous variables are:

Max Z: maximum farm profit (FCFA/ha); $\mathbf{u_c}$: activity level or cultivated land area for crop c (ha); $\mathbf{Y_c}$: yield of crop c (t/ha); $\mathbf{K_c}$: intensity of compost use on crop c (t/ha); $\mathbf{A_c}$: intensity of animal manure use on crop c (t/ha); $\mathbf{M_c}$: intensity of mineral fertilizer use on crop c (t/ha); $\mathbf{L_c}$: intensity of labour use on crop c (manday/ha); $\mathbf{W_c}$: intensity of irrigation water use on crop c (m³/ha); and the shadow prices of compost, labour and land (FCFA/unit).

The exogenous variables are (see Appendices 2 to 4):

$\mathbf{P_c}$**:** price of crop c (FCFA/t); **t:** transport rate for compost or crops (FCFA/t/km); **d:** radius or distance from the city-centre to the farm (km); $\mathbf{P_k}$**:** price of compost (FCFA/t); $\mathbf{P_a}$**:** price of animal manure (FCFA/t); $\mathbf{P_m}$**:** price of mineral fertilizer (FCFA/t); P_l: price of labour (FCFA/manday); $\mathbf{P_w}$**:** price of irrigation water (FCFA/m³); $\mathbf{P_j}$**:** price of pesticides or seeds (FCFA/kg); $\mathbf{I_{j,c}}$**:** intensity of pesticides or seeds j used on crop c (kg/ha); G: compost availability per farm per cropping year (t); **E:** labour availability per farm per cropping year (mandays); **S:** land availability per farm per cropping year (ha).

The exogenous parameters are (see Appendix 1):

$\boldsymbol{\beta_0, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5}$**:** parameters (coefficients) of the Cobb-Douglas production function for crop c. The constant coefficient is β_0 whereas $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ represent the production elasticities for compost, animal manure, mineral fertilizer, labour and irrigation respectively.

The indices are:

c: index for food crops/vegetables, that is, pepper, lettuce, tomatoes, carrots, cabbage, maize, watermelon, onion, okra, green beans and white beans; **k**: index for compost; **a**: index for animal manure; **m**: index for mineral fertilizer; **l**: index for labour; **w**: index for irrigation water; **j**: index for other inputs such as pesticides and seeds.

3.3.2 Objective Function and Constraints of the Model

The objective of the model is to maximize the profit derived from the cultivation of the 11 main food crops/vegetables grown on those farms located within a certain radius range or distance (d) from the city-centre. The algebraic notation for the objective function is presented in Equations 7-12. The maximum farm profit at a given distance (d) from the city is estimated by subtracting the costs of different categories from the total revenue gained from the 11 crops at the selected distance.

Equation (7) of the objective function calculates the gross revenue from crops. Equation (8) highlights the transport cost of the crops. Equation (9) represents the compost cost whereas Equation (10) displays the compost transport cost. Equation (11) is concerned with the following input costs (except compost) entered in the Cobb-Douglas production function: animal manure, mineral fertilizer, labour and irrigation water. Equation (12) on the last line of the objective function is related to the costs of other inputs such as pesticides and seeds not included in the Cobb-Douglas production function.

The constraints are explained by Equations (13) to (16) following the objective function. These are:

(i) The Cobb-Douglas production function (Equation 13). This function is used because of its perfect inputs substitution property, its simplicity in interpreting coefficients, and its best fitness to estimate the production elasticities of compost, animal manure, mineral fertilizer, labour and irrigation of the 11 food crops/vegetables in the survey area (see Appendix 1). As the last four inputs affect the compost property, they were included in the Cobb-Douglas production function because: *animal manure* also brings organic matter beneficial to the soil like compost, *mineral fertilizer* more rapidly releases its nutrients than compost, *labour* is in high demand on compost farms, and *irrigation* is not required as much on compost farms due to the water holding ability of compost (Jaza 2007, 2008).

(ii) The availability of compost, as indicated in Equation (14). This equation states that at a given location (situated d km from the city), the amount of compost used by any farmer in order to cultivate all the 11 food crops/vegetables should be less than or equal to the available compost quantity per farmer, per cropping year, in the study area. As mentioned earlier, if all 810 tons of daily collected household waste from Yaoundé-city is processed into compost (assuming 1 ton household waste equals 0.42 ton compost), then Yaoundé can produce roughly 124,320 tons of compost every year (that is, 810t/day*0.42t*365days=124,320t) (see Appendix 2). Each of the 1000 compost users in the rural areas surrounding Yaoundé is expected to receive on average 124,320/1000=124.320 tons of available compost per cropping year (Ministry of Agriculture 2003; Jaza 2005). This figure (124.320 tons) is close to the average amount of yearly compost availability at the disposal of the 135 surveyed farmers in the study area. Thus, it is the yearly farm compost availability used at each location in the baseline modelling exercise (see Appendix 2).

(iii) The availability of labour is shown in Equation (15), which explains that, at a given location (situated d km from the city), the amount of labour used to cultivate all the 11 food crops/vegetables should be less than or equal to the available labour amount per farmer, per cropping year, in the study area. For each location in the modelling exercise, there are 60 days of available labour, per farmer, per cropping year; this figure represents the average number of days for all the surveyed farmers located within the study area (see Appendix 2).

(iv) The availability of land area which is expressed in Equation (16). For any given distance from the city (represented by d km), the land area used to cultivate all the 11 food crops/vegetables should be less than or equal to the available land area per farmer, per cropping year, in the study area. In Equation (16), the data on available land area at each location represents the average of all the surveyed farmers within the study area, which results in an average figure of 0.61 ha for the whole study area. Thus, in the modelling exercise, 0.61 ha is the amount of available land (per year) for each location of the study area (see Appendix 2).

4. RESULTS AND DISCUSSION

In addition to the "Baseline" modelling, four scenarios were used in the von Thünen model for analysing the research questions of this study. They are: Scenarios (Sc.) 1, 2, 3 and 4, with each scenario corresponding to an increase of compost availability from the baseline amount of 124,320 t to +25%, +50%, +75%, and +100%, respectively. In absolute terms, this corresponds to an increase in the compost availability from 124,320 t (Baseline) to 155,400 t (Sc.1); 186,480 t (Sc.2); 217,560 t (Sc.3) and 248,640 t (Sc.4), respectively.

Even before the various scenarios were run, the model was validated and it was found that the baseline optimal solution from the model exactly displayed our data collected during the field survey with regards to both farm profits and compost (shadow) prices. The non-linear von Thünen model computes the optimal level of compost use (that is, compost scarcity), the compost shadow price, and the farm profit as a function of both the city-to-farm distance (km), and the compost availabilities for each scenario.

4.1 Compost Scarcity as a Function of City-To-Farm Distance and Compost Availability

By definition, a scarce resource is usually completely used up during the production process or during one cropping year, whereas a non-scarce resource is not completely used up during one production period of a single year (Debertin 1986; Doll and Orazem 1978).

Using the von Thünen model, this paper attempts to verify whether compost was a scarce or non-scarce resource as a function of city-to-farm distance and compost availability. This was assessed in the model by looking at the level of compost used as well as the amount of compost made available to the farm. Table 1 depicts the optimal amount of compost used by the farmer at each distance from the city and for each level of compost availability (Baseline and Sc.1-4).

The columned results in Table 1 can be interpreted in the same way as the compost shadow price (marginal productivity of compost), which is computed in the model on the basis of the amount of initially available compost and the optimal level of compost used by the farmer. In interpreting Table 1 (columned results), one can observe that:

a) At the Baseline scenario, the total amount of available compost used (124.320 t) with a 79 km radius implies that compost itself is a scarce resource within the area. It appears to be economically worthwhile to provide greater amounts of compost to farms located in this area since the increased supply would significantly aid local farmers. The presence of a positive compost shadow price also validates this conclusion (see next section on compost shadow price). However, for any area beyond the 79 km radius (that is >80 km from the city), all the available compost is not completely used implying that compost is a non-scarce resource in this zone. The amount of utilised compost begins to decrease as one moves beyond 80 km from the city. For farmers located more than 80 km from the city, there is no added value in purchasing additional compost because existing quantities are already sufficient. Any additional compost purchases would not be financially or logistically prudent at this zone. The incremental addition of one (1) unit ton of compost yields zero profit for the receiving farm beyond 80 km from the city. In general, the decision on whether or not an additional compost purchase is financially beneficial to the farmer depends on the city-to-farm transportation costs. Compared to farms located far away, those producers living in the vicinity of the city pay lower transportation costs to bring compost to their farms or to sell their crops in the Yaoundé city-centre. Thus, the transportation cost of compost is "cheaper" within 0-79 km, and this explains why all the available compost is used and any supplementary compost amount would still increase the farm profit in this zone (see Table 1, Column 2).

b) When compost availability is increased by 25% (Sc.1), the amount of available compost (155.400 t) is completely used at a distance range of 0-65 km from the city, implying that compost is a scarce resource in this zone. The explanation relies on the distance based-gradient analysis according to which, the shorter is the city-to-farm distance, then the cheaper would be the compost transportation cost and the more farmers at the vicinity of the city would attempt to purchase any new offer of compost in order to improve their profit. It was already stated that, at an availability of 124.320 t (Baseline), compost was a scarce resource within a 0-79 km distance range. Now that compost has increased in quantity, those farmers producing at the shortest distance from the city would like to improve their profit at first before longer-distance farmers. The former have the advantage that they can purchase compost cheaper (because of lower

Table 1: Optimal level of compost use (t) as a function of city-to-farm distance and compost availability

Distance from the city (km)	*Baseline: (124.320 t)*	*Sc.1: 25% increase compost availability (155.400 t)*	*Sc.2: 50% increase compost availability (186.480 t)*	*Sc.3:75% increase compost availability (217.560 t)*	*Sc.4: 100% increase compost availability (248.640 t)*
1	124.320	155.400	186.480	217.560	248.640
5	124.320	155.400	186.480	217.560	248.640
10	124.320	155.400	186.480	217.560	248.640
15	124.320	155.400	186.480	217.560	248.640
20	124.320	155.400	186.480	217.560	248.640
25	124.320	155.400	186.480	217.560	248.640
30	124.320	155.400	186.480	217.560	248.640
35	124.320	155.400	186.480	217.560	248.640
40	124.320	155.400	186.480	217.560	248.640
45	124.320	155.400	186.480	217.560	*244.980*
50	124.320	155.400	186.480	*216.417*	*216.417*
55	124.320	155.400	186.480	*193.445*	*193.445*
60	124.320	155.400	*174.596*	*174.596*	*174.596*
65	124.320	155.400	*158.874*	*158.874*	*158.874*
70	124.320	*145.574*	*145.574*	*145.574*	*145.574*
75	124.320	*134.176*	*134.176*	*134.176*	*134.176*
76	124.320	*132.081*	*132.081*	*132.081*	*132.081*
77	124.320	*130.045*	*130.045*	*130.045*	*130.045*
78	124.320	*128.066*	*128.066*	*128.066*	*128.066*
79	124.320	*126.142*	*126.142*	*126.142*	*126.142*
80	*124.270*	*124.270*	*124.270*	*124.270*	*124.270*
85	*115.626*	*115.626*	*115.626*	*115.626*	*115.626*
90	*108.023*	*108.023*	*108.023*	*108.023*	*108.023*
95	*101.287*	*101.287*	*101.287*	*101.287*	*101.287*
100	*95.281*	*95.281*	*95.281*	*95.281*	*95.281*
110	*85.041*	*85.041*	*85.041*	*85.041*	*85.041*
120	*76.646*	*76.646*	*76.646*	*76.646*	*76.646*
130	*69.648*	*69.648*	*69.648*	*69.648*	*69.648*
140	*63.732*	*63.732*	*63.732*	*63.732*	*63.732*
150	*58.670*	*58.670*	*58.670*	*58.670*	*58.670*
175	*48.745*	*48.745*	*48.745*	*48.745*	*48.745*
200	*41.492*	*41.492*	*41.492*	*41.492*	*41.492*
300	*25.337*	*25.337*	*25.337*	*25.337*	*25.337*
400	*17.766*	*17.766*	*17.766*	*17.766*	*17.766*

In this Table:
(i) Baseline=124.320 t/year of current compost availability; Scenario=Sc.; Sc.1=25% increase of compost availability (155.400 t/year); Sc.2=50% increase of compost availability (186.480 t/year); Sc.3=75% increase of compost availability (217.560 t/year); Sc.4=100% increase of compost availability (248.640 t/year).
(ii) At a given compost availability level (Sc.), the horizontal line separates the locations where compost use is exhausted (normal font) with *non-exhausted compost use locations.*

transportation costs from their shorter distance to the city). The incremental addition of one (1) unit ton of compost yields higher profit for short-distant farmers. Hence, those farmers at the vicinity of the city will benefit from this advantage and take all the supplementary compost amount furnished in their farm areas. Doing so, all the compost supplied will be exhausted at a shorter distance and the supplementary amount offered would not suffice for all farmers within 0-79 km who want this surplus. The model shows that the exhaustion of compost would occur within 0-65 km. However, for farms located more than 70 km from Yaoundé, the model shows that the amount of compost actually used is smaller than the amount of compost which was made available to farmers. Thus, compost is a non-scarce resource in this area (70-400 km). A key observation made during this study was that the compost used by the model decreases as one surpasses a 70 km radius. Therefore, the researchers believe it is economically profitable to deliver surplus compost only to those farms located within a 65 km distance from the city; there is no financial profit to be gained for those farmers located beyond a 70 km distance from Yaoundé (see Table 1, Column 3).

c) When compost availability is increased by 50% (Sc.2), all 186.480 t of it is used within a 55 km radius from the city-centre implying that compost is a scarce resource in this zone. In economic terms, this translates to a marginal cropping revenue that is *equal to* the marginal compost cost for those farms located within the 55 km area. However, one part of the compost remains unused for regions situated farther away than 55 km, demonstrating that compost is not exhausted (that is, it is a non-scarce resource in this location). Any farm located within 55-400 km from the city will find that their surplus amounts of unused compost will result in a marginal cropping revenue that is *less than* the marginal compost cost, therefore making the increase in compost availability economically unsound (see Table 1, Column 4).

d) When compost availability is increased by 75% (Sc.3), all 217.560 t of it is used within a 45 km radius from the city-centre, justifying the scarcity of compost resource in this zone. However, the pattern is the same here as in the previous two scenarios: the amount of utilised compost begins to decrease for any farm located beyond 50 km from the city. The same economic rationale also applies, in that the marginal revenue from cropping activities is *equal to* the marginal cost of compost resource used to produce crops, but *only* for those areas located within the 50 km radius. But for localities situated beyond a 50 km radius from the city, compost is not fully used because the marginal revenue from cropping activities is *less than* the marginal cost of compost resource used to produce crops. The non-exhaustion of compost demonstrates that it is a non-scarce resource for farmers cultivating in this zone (see Table 1, Column 5).

e) When the compost availability is doubled (that is, increased by 100%) (Sc.4), all 248.640 t of it is used by the farmers located within 40 km of the city, implying that the resource of compost is scarce in this zone. However, for any farm located 45 km or more from the city, this is no longer the case and unused amounts of compost remain. The presence of surplus amounts of compost demonstrates that compost is not exhausted (that is, it is a non-scarce resource) and thus it would be wasteful if transported to farmers located beyond the 45 km radius. The economic interpretation is the same as explained in previous scenarios (see Table 1, Column 6).

When looking at all the scenarios together (Table 1, Columns 1-6), one can see that as more compost is available (from Baseline to Sc.1-4), compost becomes more scarce at shorter distances. The "cut-off distance" is the location from which point the compost begins to be non-scarce as one moves further away from the city-centre. Within each column of Table 1, the horizontal line is the "cut-off distance" which separates the locations where compost use is exhausted with non-exhausted compost use locations. Generally, the "cut-off distances" decrease in tandem with the corresponding compost increases: the "cut-off distance" declines at first from 80 km to 70 km, then to 60 km, then to 50 km and finally to 45 km as compost availability increases by 25%, 50%, 75% and 100%, respectively (see Table 1).

In Appendix 1, the compost production elasticity is less than one for each crop, implying a decreasing return of crop yield with respect to compost intensity (that is, by doubling the compost intensity the crop yield would increase by less than the double). This means that to obtain double the amount of crop yield, we need more than double the compost intensity (larger compost amount). Because of lower transportation costs due to their proximity to the city (that is, the fact that the incremental addition of one (1) unit ton of compost yields higher profit), every short-distance farmer would like to increase his/her crop yield/farm returns, and as a result a large compost amount is applied to the land to achieve this goal. As a result, when compost availability is increased (from Baseline to Sc.1-4, Table 1), all short-distance farms will struggle to get the supplemental compost made available in their locations and it will not suffice for all of them. As shorter-distance farmers can travel more rapidly to the city than their neighbours farther away, they will purchase all the compost first. This explains why compost becomes scarcer at shorter city-to-farm distances when a greater amount is available (see Table 1).

Since the amount of utilised compost vis-à-vis the available compost helps the model compute the compost shadow price, identical "cut-off distances" are also displayed from the shad-

Table 2: Compost shadow price[a] (000 FCFA/t) as a function of city-to-farm distance and compost availability

Distance from the city (km)	*Baseline: (124.320 t)*	*Sc.1: 25% increase compost availability (155.400 t)*	*Sc.2: 50% increase compost availability (186.480 t)*	*Sc.3:75% increase compost availability (217.560 t)*	*Sc.4: 100% increase compost availability (248.640 t)*
1	31.940	26.320	22.460	19.640	17.480
5	30.320	24.710	20.850	18.030	15.870
10	28.300	22.690	18.840	16.020	13.860
15	26.270	20.670	16.820	14.000	11.840
20	24.250	18.650	14.810	11.990	9.830
25	22.230	16.640	12.790	9.980	7.820
30	20.210	14.620	10.780	7.960	5.810
35	18.190	12.600	8.760	5.950	3.800
40	16.160	10.580	6.750	3.940	1.780
45	14.140	8.570	4.730	1.920	*EPS*
50	12.120	6.550	2.720	*EPS*	*EPS*
55	10.100	4.530	0.700	*EPS*	*EPS*
60	8.080	2.510	*EPS*	*EPS*	*EPS*
65	6.050	0.500	*EPS*	*EPS*	*EPS*
70	4.030	*EPS*	*EPS*	*EPS*	*EPS*
75	2.010	*EPS*	*EPS*	*EPS*	*EPS*
76	1.610	*EPS*	*EPS*	*EPS*	*EPS*
77	1.200	*EPS*	*EPS*	*EPS*	*EPS*
78	0.800	*EPS*	*EPS*	*EPS*	*EPS*
79	0.390	*EPS*	*EPS*	*EPS*	*EPS*
80	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
85	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
90	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
95	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
100	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
110	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
120	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
130	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
140	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
150	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
175	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
200	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
300	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*
400	*EPS*	*EPS*	*EPS*	*EPS*	*EPS*

In this Table:
(i) [a]The compost shadow price is endogenously computed in the model. Thus, in order to get this shadow price from our model, we have put zero as the compost price and thus the compost cost is also zero.
(ii) EPS (Epsilon) denotes that the shadow price is not exactly zero, but very near to zero.
(iii) The scenarios (Sc.) are defined exactly as in Table 1.
(iv) At a given compost availability level (Sc.), the horizontal line separates the location where shadow price is positive (normal font) with *nearly zero shadow price.*

ow price results. The results of Table 2 and its graphical representation in Figure 2 clearly support this conclusion.

4.2 Compost Pricing: Impact of an Increase in Availability on Shadow Price

A shadow price is the maximum price that a farmer is willing to pay for an extra unit (ton) of compost. It represents the amount by which the farm profit would increase if one more unit (ton) of compost were made available. A shadow price is also referred to as marginal productivity because its value compares the marginal revenue per unit of crop activity to the marginal cost of compost used to produce one unit of crop activity (Hazell and Norton 1986). Two situations are generally observed:

(1)-If the marginal revenue is *equal to* the marginal cost (that is, revenue exhaustion), then

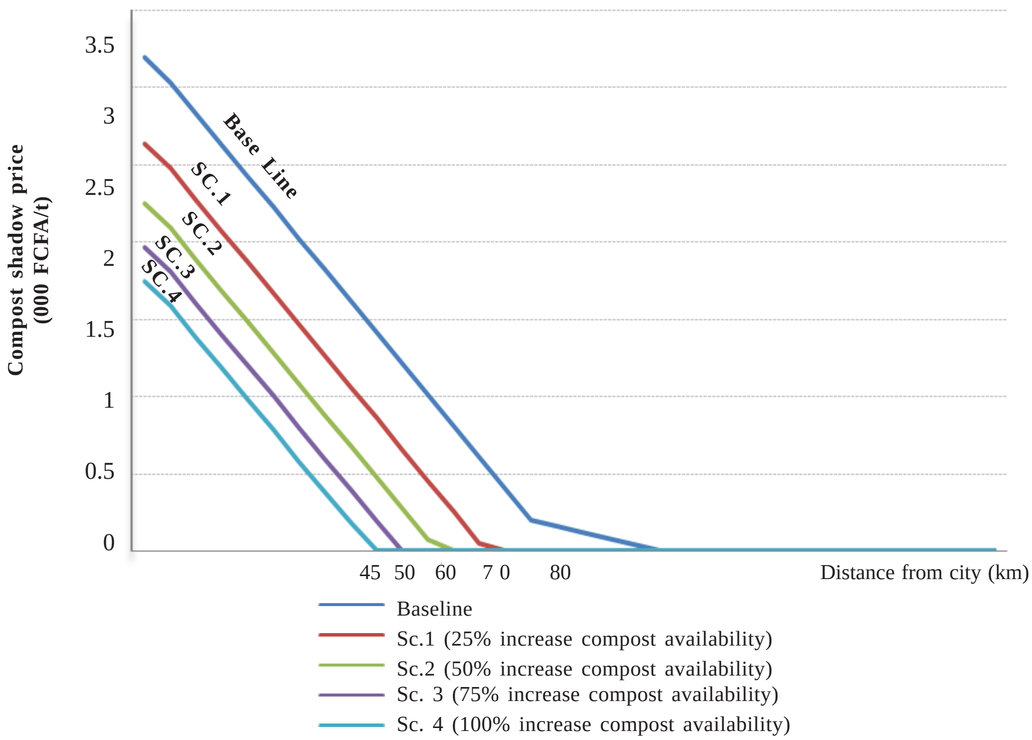

Fig. 2. Compost shadow price (0000 FCFA/t) as a function of city-to-farm distance and compost availability

the available compost resource is fully used (scarce) and the marginal productivity is positive, as is the compost shadow price.

(2)-If the marginal revenue is *less than* the marginal cost (that is, no revenue exhaustion), then the available compost resource is not fully used (non-scarce) and the marginal productivity (shadow price) is zero. In cases where the shadow price is not exactly zero, but very near to zero, the GAMS will denote it in its language as an EPS (*Epsilon*) value.

In this paper, the compost shadow price has been computed as a function of the farm's distance from the city and the compost availability; its results are displayed in Table 2. Those results can be interpreted either by Column or by Row.

For example, at a 1 km distance from the city (Table 2, Row 1), the Baseline compost shadow price of 31.940 thousand FCFA/t suggests that a farmer should pay *no more than* 31.940 thousand FCFA a ton for additional compost. Compost cost of *less than* 31.940 thousand FCFA/t will increase the farm profit. Compost cost of *more than* 31.940 thousand FCFA/t will decrease the farm profit. Compost cost of *exactly* 31.940 thousand FCFA/t will cause the farm profit to remain the same.

Otherwise interpreted, the Baseline compost shadow price of 31.940 thousand FCFA/t (Table 2, Row 1) suggests that, if one (1) more ton of compost were to be made available to the farmers, the farm profit would increase by 31.940 thousand FCFA (passing thereby from 421.000 to 452.940 thousand FCFA) per hectare of cultivated land. At the same distance of 1 km from the city, the computed shadow prices from Sc.1 to 4 indicate that the farm profit would increase by 26.320, 22.460, 19.640 and 17.480 thousand FCFA per hectare of cultivated land when the compost availability is increased by 25%, 50%, 75% and 100%, respectively (see Table 2).

By carefully looking at each Row of Table 2, six sub-cases are observed when all the scenarios (Baseline and Sc.1-4) are taken together:

a) When compost quantities are incrementally increased for farms located 1-40 km from the city, the compost shadow price will decrease; however, the price will still remain positive (greater than zero) in all cases (see Table 2).

b) At 45 km from the city, the compost shadow price will remain positive as long as the increase in compost is less than or equal to 75%. Once compost availability is increased by 100%, the price will stand at an EPS value (see Table 2).

c) Within 50-55 km from the city, a positive compost shadow price is associated with any compost increase of up to 50%. However, an increase from 75-100% will result in the price standing at an EPS value (see Table 2).

d) Within 60-65 km from the city, a positive compost shadow price is maintained as long as compost increases are 25% or below. Once the increases reach between 50-100%, the price adopts an EPS value (see Table 2).

e) At each location situated at a distance ranging between 70-79 km from the city, the compost shadow price is greater than zero at the Baseline solution but changes to an EPS value when there is an increase of compost availability ranging from 25% to 100% (see Table 2).

f) For areas located more than 80 km from the city, the compost shadow price takes an EPS value for all cases (that is, either for the Baseline scenario or for any increase of compost availability by 25%, 50%, 75% and 100%) (see Table 2).

By observing the column results in Table 2, each level of compost availability (Baseline and Sc.1 through 4) gives rise to a different "cut-off distance" from which point the model will recommend an EPS value for the compost shadow price. The "cut-off distance" is the distance in km from which point it is no longer profitable to transport additional quantities of compost to the farms. In Table 2, the profitable "cut-off distance" (as separated by a horizontal line within each column) changes in conjunction with the amount of available compost. This line splits the location where the shadow price is positive with the zone where the shadow price adopts an EPS value. Each scenario gives rise to a different border-line/cut-off distance from which it would no longer be economically beneficial for the farmers to receive additional shipments of compost.

Figure 2 provides a graphical representation of these cut-off distances using the computed compost shadow prices (as a function of the city-to-farm distance and compost availability). The horizontal axis of Figure 2 depicts the cut-off distances of 80 km, 70 km, 60 km, 50 km and 45 km for the Baseline, and 25%, 50%, 75% and 100% of compost availability increase, respectively. Hence, the cut-off distance decreases as compost availability increases (see Table 2 and Fig. 2).

At the Baseline scenario (124.320 t/year of compost availability), the cut-off distance of 80 km implies that it is not recommended to transport additional compost to farms located at a distance *farther away than* 80 km from the city because this supplementary amount would not result in any additional farm profit. This explains why the shadow price takes an EPS value within the radius range of 80-400 km. However, it would be advisable to bring supplementary compost amounts to farmers cultivating crops *within* an 80 km radius from the city because the shadow price is positive. Similar interpretations apply to the cut-off distances of 70 km, 60 km, 50 km and 45 km and their corresponding increases in compost availability of 25%, 50%, 75% and 100% (Sc.1 to 4), respectively.

In general, by looking at each row of Table 2, at a given distance from the city, it appears that the shadow price of compost decreases as compost availability is increased from the Baseline until 25-100%. In Row 1 (at 1 km distance from the city) for example, the shadow price of compost decreases at first from 31.940 to 26.320, then to 22.460, then to 19.640 and finally to 17.480 thousand FCFA/t as compost availability is increased from the Baseline to 25%, 50%, 75% and 100%, respectively. Standard demand and supply economic theory explains these results (see Fig. 3). At a given time period, the compost supply (S) is fixed/given and assumed to be perfectly inelastic in Yaoundé-city. The compost demand (D) in rural areas is elastic because it is directly related to the city-to-farm distance. As illustrated graphically (Fig. 3), an increase of the compost availability implies an increase of the compost supply quantity from Q_1 to Q_2, or simply is a shift of the compost supply curve from S_1 to S_2. This shift in turn will lead to a movement of the intersection (or equilibrium) point of the D and S curves and therefore the (shadow) price for compost will decrease from P_1 to P_2 (see Fig. 3). Hence, the more Yaoundé household waste that is generated and composted, the less scarce it becomes, thus resulting in a lower compost shadow price.

Those findings are similar to those of a 2005 study by Jaza which found that the compost shadow price decreases by 21-54% when the

Yaoundé compost availability is increased by 25-100% (Jaza 2005). In economic terms of decreasing returns to scale, when greater amounts of compost are provided, the marginal productivity of compost (the compost shadow price) decreases; the Cobb-Douglas production elasticity of the compost variable is less than one (1) for each crop (see Appendix 1). The various measures of production elasticity for the compost suggest that (Appendix 1) a 1% increase in compost quantities would yield an increase of 0.168-0.259% for all crops. By further increasing the compost availability/intensity by 25-100%, the yield of crops would increase by 4.2-25.9%, that is, [(25*0.168)-(100*0.259)]%, but at a decreasing rate which explains the decreasing marginal productivity of compost (compost shadow price).

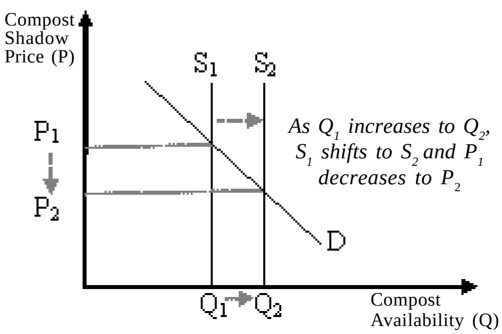

Fig. 3. Effect of the increase of compost availability on the shadow price

In the field, one could also reduce the compost price by advertising the source separation of organic waste at each household level. Currently, because Yaoundé household waste is not source separated (a single trashcan is used to collect organic residues, plastic, glass, paper, metal, cloth, etc.), the labour cost of separating its organic component prior to composting contributes more than 38% of the total cost to make compost (Ngnikam 2000). Thus, source separation could help to reduce the composting cost and the compost price so as to make it more attractive for farmers (Jaza 2005).

4.3 Impact of Increased Compost on Farm Profit

The farm profit figures displayed in Table 3 reveal that for all scenarios (that is, Baseline and Sc.1-4), the availability of compost for crop production yields a positive profit for distances less than 80 km from the city. Within this zone, the revenue gained from cropping activities is higher than the costs of production. The difference between revenue and costs is positive, and hence it is advisable for farmers within this range to use compost for crop cultivation (see Fig. 4).

However, for farms located 80 km or more from the city, the revenue gained from the sales of crops is lower than the costs of all variable inputs (including compost) to produce crops. Because the difference between revenue and costs of production is negative, so is the farm profit. The column results in Table 3 show that these decreases in farm profit are greater as one moves further away from the city (see Fig. 4). It would therefore be neither economically profitable nor advisable for farmers to cultivate crops using compost in farms situated at a distance farther away than 80 km from the city.

Using the Baseline scenario (that is, an initial starting amount of 124.320 t of compost), one observes an inverse relationship among farm profit and farm distance. As displayed in Table 3, a 1 km distance from the city corresponds to a farm profit of 421,000 FCFA/ha, while at 79 km, only a 5,000 FCFA/ha farm profit is recorded, respectively. However, from 80-400 km from the city, only negative farm profits are earned, which range from losses of -0.3745 FCFA/ha at 80 km to -645,000 FCFA/ha at 400 km (see Table 3). Hence, the study hypothesis is validated and one can say that agricultural farms located closer to the city gain more benefit from using compost for crop production than those located farther away. The decrease in farm benefit is proportional to the distance from the city because of the increasing transport costs of compost and crops.

Moving beyond the Baseline figures to those of Sc.1 through 4 (that is, compost increases of 25-100%), the ranges of positive and negative profits (as a function of distance) are the same as those displayed in the Baseline (positive profits within a 0-79 km radius, and negative profits within an 80-400 km range) (see Table 3 and Fig. 4). An important observation was made while examining the row data, namely that as compost availability increases (from Baseline to Sc.1-4), the farm profit earned at each location within 1-76 km increases (see Table 3 and Fig. 4). For example, at any given distance less than 77 km

Table 3: Farm profit[b] (000 FCFA/ha) as a function of city-to-farm distance and compost availability

Distance from the city (km)	*Baseline: (124.320 t)*	*Sc.1: 25% increase compost availability (155.400 t)*	*Sc.2: 50% increase compost availability (186.480 t)*	*Sc.3:75% increase compost availability (217.560 t)*	*Sc.4: 100% increase compost availability (248.640 t)*
1	421	511	587	652	709
5	400	485	555	616	668
10	373	452	516	570	616
15	347	419	477	525	565
20	320	386	438	479	513
25	293	353	398	434	461
30	266	320	359	388	409
35	240	287	320	343	358
40	213	254	281	297	306
45	186	221	241	252	254
50	160	188	202	206	206
55	133	155	163	163	163
60	106	122	125	125	125
65	80	89	89	89	89
70	53	57	57	57	57
75	26	27	27	27	27
76	21	22	22	22	22
77	16	16	16	16	16
78	10	10	10	10	10
79	5	5	5	5	5
80	*-0.3745*	*-0.3745*	*-0.3745*	*-0.3745*	*-0.3745*
85	*-26*	*-26*	*-26*	*-26*	*-26*
90	*-50*	*-50*	*-50*	*-50*	*-50*
95	*-73*	*-73*	*-73*	*-73*	*-73*
100	*-94*	*-94*	*-94*	*-94*	*-94*
110	*-134*	*-134*	*-134*	*-134*	*-134*
120	*-170*	*-170*	*-170*	*-170*	*-170*
130	*-202*	*-202*	*-202*	*-202*	*-202*
140	*-232*	*-232*	*-232*	*-232*	*-232*
150	*-260*	*-260*	*-260*	*-260*	*-260*
175	*-321*	*-321*	*-321*	*-321*	*-321*
200	*-374*	*-374*	*-374*	*-374*	*-374*
300	*-533*	*-533*	*-533*	*-533*	*-533*
400	*-645*	*-645*	*-645*	*-645*	*-645*

In this Table:
(i) [b]The farm profit is equal to the revenue *minus* crop transport cost *minus* compost cost *minus* cost variables Cobb-Douglas function (except compost) *minus* cost of seeds and pesticides.
(ii) Baseline=124.320 t/year of current compost availability; Scenario=Sc.; Sc.1=25% increase of compost availability (155.400 t/year); Sc.2=50% increase of compost availability (186.480 t/year); Sc.3=75% increase of compost availability (217.560 t/year); Sc.4=100% increase of compost availability (248.640 t/year).
(iv) The horizontal line inside the Table separates the optimal profitable locations (normal font) with *non-profitable locations.*

from the city, a higher farm profit will be recorded in Sc. 4 than in Sc.3, and a higher profit in Sc.3 than Sc.2, etc. (see Table 3).

For example, at a 1 km distance from the city, the farm profit for Sc.1-4 will be higher than those of the Baseline as it increases from 421,000 to 709,000 FCFA/ha when compost availability is increased from the Baseline to 100% (see Table 3). Those findings are similar to a previous study by Jaza (2005), that reported an increase in producer surplus from 9.07 to 28.66% when compost availability was increased from 25 to 100% in the villages surrounding Yaoundé.

The economic explanation of these results is derived from Table 2 and Figure 3 according to which the compost (shadow) price decreases when more compost is made available to the farmers. When the compost (shadow) price is lower, more farmers are able to purchase compost for crop cultivation and fertilization, which in turn helps raise their ability to generate higher farm profits. Therefore, it is recommended that policy

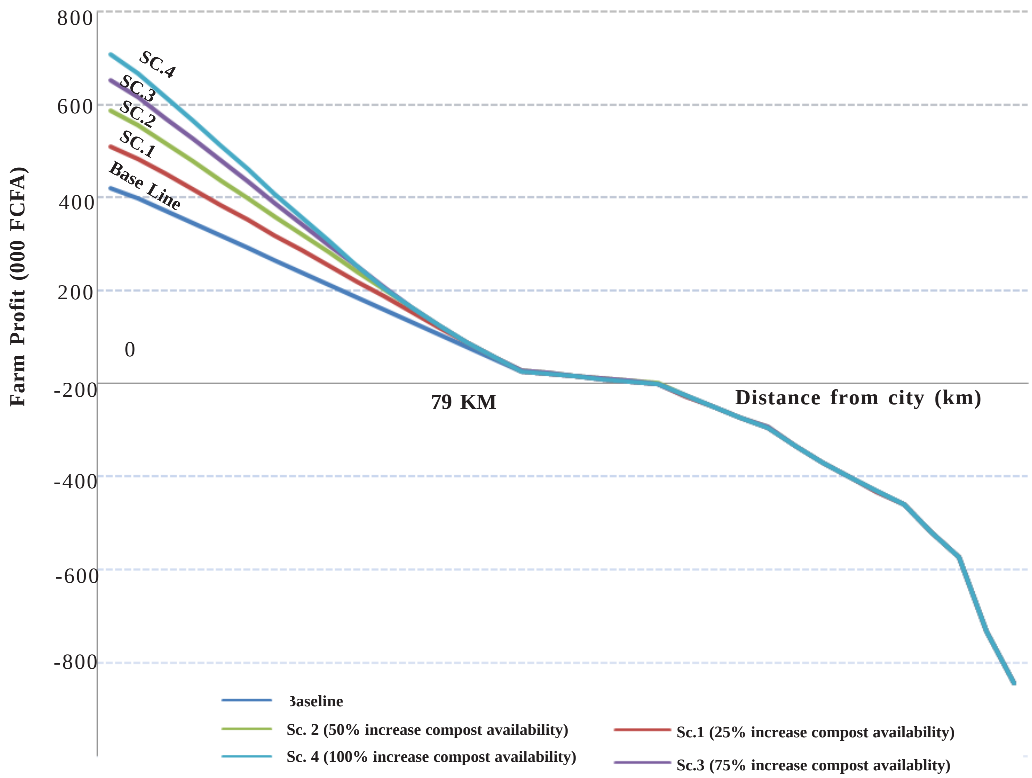

Fig. 4. Farm profit (000 FCFA/ha) as a function of city-to-farm distance and compost availability

makers assist farmers located farther from the city-centre by making more compost available to them so that they may increase their profits. This could be done by developing roads and infrastructure or by organizing farmers into co-operatives to transport compost at lower rates.

However, as demonstrated in Table 3 and Figure 4, the farm profit is the same for any farm located beyond the 77 km delineation and this applies to all Scenarios (including the Baseline). Thus, as demonstrated in Table 2, an EPS shadow price is associated with any area beyond 77 km for all scenarios, which demonstrates that there is no incremental profit to be earned from an increase in compost quantities for this area.

Figure 5 depicts an aerial “bird’s eye view” of the optimal profitable and non-profitable locations from the von Thünen model. As previously explained, the profitable farm locations are within a 0-80 km range of the city, and the non-profitable ones within an 80-400 km range (see Table 3; Figs. 4 and 5). These findings are similar to previous studies made by Ndoumbé (1994) and Ngnikam (2000), each of whom found that, on average, the compost produced in Yaoundé is used within a 100 km radius surrounding the city-centre. More precisely, 80% of the produced compost is used in a radius of less than 20 km surrounding Yaoundé while 19% is used within a radius range of 20-80 km from the city, and 1% is used in a radius between 80 and 100 km surrounding the city-centre. Beyond 100 km from the city, there were hardly any registered compost users/farmers (Ngnikam 2000).

In analyzing the results of this study, it is important to take note of the following factors that can affect both farm profit and profitability zones:

a) The organic property of compost is such that its nutrients can be released for a period of up to three years (that is, six cropping seasons[2]). However, because these long-term benefits are often difficult to quantify, our model assumed a compost benefit that extended only through the

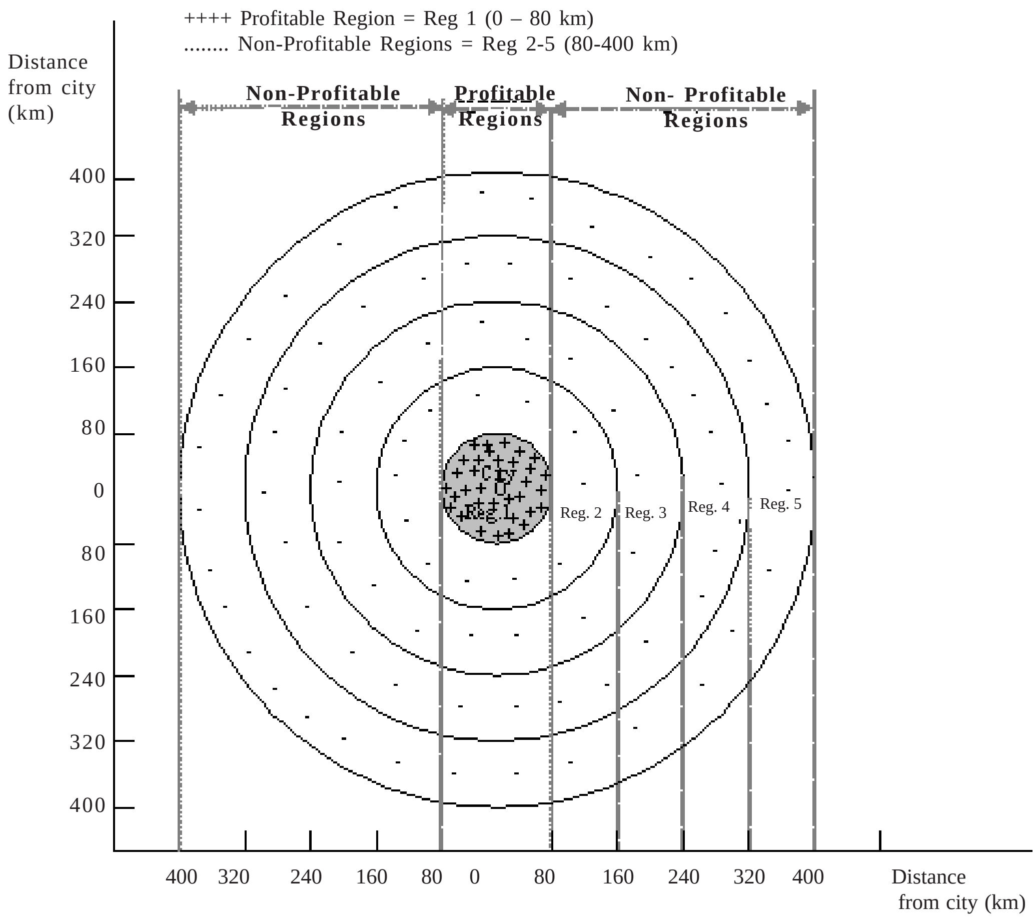

Fig. 5. Aerial "bird's eye view" of the optimal profitable and non-profitable locations from the von Thünen model

first season of compost application. Had a longer time span been considered and calculated, we would have most likely seen higher profit gains for farmers at each location as well as a cut-off distance that exceeded 79 km.

b) Municipality cars owned by the city of Yaoundé (often used to transport city trash to local dumping sites) could transport compost to surrounding farms either free of charge or at subsidized rates.

c) Some field distances as measured by GIS (Geographic Information System) are shorter than the linear distances recorded in the model, making it possible to record even higher farm profits and thus strengthening our conclusions.

d) The environmental benefits gained from composting household waste were not taken into account in the von Thünen model. The pollution costs from waste handling and related diseases would be lower if all of the Yaoundé household waste is composted and transported for rural farming activities. Composting organic waste would not only improve the farm profit, but it would provide intangible health benefits to all Yaoundé residents.

5. CONCLUSION

With a growing urban population and a current output of 810 tons of organic household waste per day, Cameroon's capital of Yaoundé is capable of producing up to 124,320 tons of compost per year. Although it is the second largest city in the country, Yaoundé lacks proper roads and transportation infrastructure, which limits the transfer of compost to surrounding farm areas.

A von Thünen model was developed in this study to analyze the issue. The results of this study show that the farm profit gained from using Yaoundé-generated compost for crop cultivation decreases as one moves away from the city. This paper tested and validated the hypothesis that agricultural farms located closer to the city derive greater benefit from using compost for crop production than those located farther away. In its Baseline and Scenarios results, the model displays the optimal profitable range to be 0-79 km from the city-centre, while the non-profitable locations are those within 80-400 km; the borderline of 79 km is referred to as the "cut-off distance" as it is not advisable or economically profitable to deliver compost to farms beyond this range. Up until this point however, compost is scarce and all the available compost is fully used for crop production/fertilization.

We concluded that it would not be profitable to deliver compost to farms located within the 80-400 km radius, a finding which was confirmed by the steadily declining compost shadow prices as one moves farther away from Yaoundé. Within 0-79 km the shadow price is positive, but beginning at the 80 km delineation it hovers close to zero. One of the main factors accounting for the decreasing farm profit is the high transport costs associated with delivering bulky amounts of compost to the more distant farms.

6. RECOMMENDATIONS

Since the von Thünen model suggests delivering compost to farms within the 0-79 km radius, we recommend that the Cameroonian Ministry of Agriculture advertise the substitution of mineral fertilizer by compost within the 0-79 km radius. To make compost more affordable for farmers located beyond the 79 km cut-off distance, the Cameroonian Ministry of Agriculture should consider subsidizing part or all of the compost transportation costs, using tax revenues from Yaoundé residents in order to fund the subsidy. Encouraging the formation of farm cooperatives to address transportation issues would facilitate group problem-solving and create a common voice to be heard by the local government, both of which would hopefully help improve farm profits and efficiency.

The results from the various Scenarios (1-4) show that an increase in compost availability leads to a decrease in the compost shadow price. Following the laws of supply and demand, the greater the amount of Yaoundé waste that is composted and generated, the less scarce it becomes, thus resulting in a lower compost shadow price. This is especially true for those regions located farther away from the city-centre. Within each Yaoundé household, the advertisement of the source separation of organic component of household waste (which is currently inexistent) could also lower the composting cost and compost price so as to make it more attractive for farmers.

However, the farm profit and profitability zones can change by considering the following factors in the von Thünen model: (a) the organic matter/long term property of compost, (b) the involvement of Yaoundé municipality cars on compost transportation at subsidized rates, (c) the measure of shorter field distances with GIS (Geographic Information System), and (d) the environmental benefits (decreased pollution and related diseases) gained from composting household waste. However, because data was unavailable and some of these factors were difficult to quantify, the model that was developed in this study did not take these factors into account. However, had these factors been considered, it is likely we would have seen higher profit gains for farmers at each location as well as a cut-off distance that exceeded 79 km.

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NOTES

1. The Cameroonian local currency is: FCFA (*Franc des Colonies Françaises d'Afrique*). Its conversion rate is: 1Euro=655.957 FCFA.
2. One cropping season = six months = one cycle of production.

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APPENDICES: ASSUMPTIONS AND DATABASE OF THE VON THÜNEN MODEL

Appendix 1: Constant and production elasticities (å) estimated from the Cobb-Douglas production function of the main crops as included in the von Thünen model

Crops	*Constant*	*å Compost*	*å Animal manure*	*å Mineral fertilizer*	*å Labour*	*å Irrigation*
Pepper	0.101***	0.182***	0.033	0.035***	0.082**	0.178***
Lettuce	4.229***	0.237***	0.022**	0.023***	0.021**	0.177***
Tomatoes	5.501***	0.259***	0.059***	0.021*	0.025**	0.109***
Carrots	8.125***	0.242**	0.025**	0.109*	0.026*	0.102***
Cabbage	4.953***	0.169***	0.041*	0.113***	0.003**	0.156***
Maize	1.530**	0.168***	0.061**	0.124***	0.071**	0.107***
Watermelon	4.826***	0.276***	0.053	0.059**	0.068**	0.167***
Onion	6.347***	0.230***	0.049*	0.106***	0.101*	0.198***
Okra	1.893***	0.206***	0.010**	0.033*	0.128**	0.171**
Green beans	3.418***	0.235***	0.087**	0.108***	0.069**	0.234***
White beans	0.026***	0.199***	0.136***	0.120***	0.023**	0.190***

*** Significant at 1 % ** Significant at 5 % * Significant at 10 %

Appendix 2: Availability of land, labour and compost per farm per year as included in the von Thünen model

Resource availabilities	*Average availability per farmer per cropping year in study area*
Land (ha)	0.61
Labour (mandays)	60
Compost (t)	124.320

Appendix 3: Transport rate and prices of different inputs as included in the von Thünen model

Items	*Average for study area*
Transport rate of compost or crops (FCFA/t/km)	40
Compost price (FCFA/t)	0
Animal manure price (FCFA/t)	30,000
Mineral fertilizer price (FCFA/t)	200,000
Labour price (FCFA/manday)	1,500
Irrigation-water price (FCFA/m³)	337
Pesticides price (FCFA/kg)	4,450

Note: The compost shadow price is endogenously computed in the model. Thus, in order to get this shadow price from our model, we have put zero as compost price.

Appendix 4: Crop and seed prices and the intensity of utilization of seeds and pesticides as included in the von Thünen model

Crops	*Crop price (FCFA/t)*	*Seed price (FCFA/kg)*	*Seed intensity of utilisation (kg/ha)*	*Pesticide intensity of utilisation (kg/ha)*
Pepper	1,000,000	66,250	1.5	0.25
Lettuce	339,000	80,000	0.8	0.25
Tomatoes	200,000	80,000	0.1	0.25
Carrots	100,000	55,000	0.1	0.25
Cabbage	80,000	85,000	0.1	0.25
Maize	100,000	1,700	20	0.25
Watermelon	100,000	70,000	0.7	0.25
Onion	100,000	80,000	0.02	0.25
Okra	500,000	86,250	5	0.25
Green beans	200,000	400	100	0.25
White beans	600,000	700	50	0.25