Assessing the impact of infectious disease outbreaks on agriculture and food security: The case of the Ebola virus disease outbreak in West Africa

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ABSTRACT

Assessing the field level impact of Emerging Infectious Disease outbreaks such as the recentEbola virus disease (EVD) on agriculture and food security is challenging because such epidemics restrict access to farms and households, limiting the traditional means of direct measurements and field surveys. Therefore, a simulation model is developed and used to assess the impact of EVD outbreak on the 2014 agricultural production in Guinea, Liberia and Sierra Leone. Model results show that the impact of of EVD on the 2014 agricultural production was relatively small at the national level. However, it is significant at the sub-national level in affected areas. Furthermore, the impact on economic activities and livelihoods severely affected household food security in the main affected areas.

Keywords: Emerging Infectious Disease outbreak, Ebola, agriculture, simulation model, West Africa.

1. Introduction

Emerging infectious diseases (EIDs) are increasing in frequency, posinga significant threatto global economies and public health (Jones, K et al 2008;Pike, J. et al). Joneset al. (2008) found that EID events aredominated by zoonoses (60.3% of EIDs) with the majority of them (71.8%) originating in wildlife, for example, severe acute respiratory virus and Ebola virus. Infectious diseases account for a quarter to a third of all mortality and the outbreakscan easily cross borders and threaten economic and regional stability, as has been demonstrated in last decadeby HIV/AIDS, 2009 H1N1 influenza, H5N1, and SARS epidemics and pandemics as well as the recent Ebola outbreak (Verikioset al. 2011).

EIDs can be classified in two broad categories based on the nature of the outbreak and the main channel of impact. Estimates of the economic cost of outbreaks of the first category follow the standard "cost of illness" approach that focuses on the opportunity cost of resources consumed or lost as a result of disease. One example of such pandemic is HIV-AIDS, the economic cost of which arises mostly from the high mortality and illness caused by the pandemic. By contrast, outbreaks of the second category cause relatively little illness and death but short-lived and severe economic impact, driven essentially by the behavioral effects of these outbreaks. The last outbreak of Severe Acute Respiratory Syndrome (SARS) in 2003, the 1994 plague outbreak in Surat, India, or the 2014 Ebola outbreak in West Africa , fall in this category(Brahmbhatt, M;&Dutta, A; 2008). The SARS outbreak caused significant disruption and economic loss worldwide, and is estimated to have reduced worldwide GDP by USD 40 billion in 2003 (McKibbin, 2004). Similarly, the overall economic loss associated with the 1994 plague outbreak in Surat, India, were put at over USD 2 billion. According to the World Bank, the last Ebola virus disease (EVD) outbreak in West Africa caused GDP growth to fall drastically to 0.5 percent in Guinea from 4.5 percent expected before the Ebola crisis. Similarly, GDP growth fell by more than half, from 5.9 percent to 2.2 percent in Liberia and from 11.3 percent to 4.0 percent in Sierra Leone. The EVD outbreak caused severe disruptions that affect all economic sectors, notably the agricultural and food sector.Avian influenza outbreaks also cause serious disruptions to various economic sectors but the principal impact has occurred in the poultry sector. HPAI of the H5N1 strain has inflicted severe direct economist costs to affected countries, mostly in terms of losses of poultry due to the disease and control measures such as culling birds, with impacts extending not only to farmers but also to upstream and downstream sectors such as poultry traders, feed mills, breeding farms etc. Vietnam and Thailand lost about 15% of the stock of poultry (Brahmbhatt, 2005). The major affected South-East Asian economies have seen direct costs, in the region of 140 million birds culled and the stated costs of containing the epidemic of approximately USD 10 billion. In addition, trade restrictions led to a 36.8 percent decline in South-East Asian poultry trade (World Bank, 2005; Elci, 2006).

Recent years have seen a renewed interest in the analysis of the economic impact of EIDs. In the case of SARS for example, analyses have focused on the macro-economic impact including on GDPs, trade and Government budget, and most studies have highlighted the impact on sectors such as health, tourism, hotels, airlines, IT, etc(Keogh-Brown, M. R.&Smith, R. D.; 2008).Most analysis of the impact of EIDs on the agricultural sector has focused on describing changes in production and other parameters before and after the outbreak. For example, FAO conducted a number of studies on the impact ofHIV-AIDS on the agricultural sector (FAO, 2003), which found that the main channel of impact has been through loss of labour, which affects planted areas and yields resulting in reduced food production and resulting food insecurity.For example, in Zimbabwe, according to surveys conducted in 1997, agricultural output in communal areas declined by nearly 50% among households affected by AIDS in relation to households not affected by AIDS. A similar approach was used by Yalcin et al (2010) to analyze the impact of the highly pathogenic avian influenza H5N1 outbreak among turkey producers.

In case of an EID outbreak with potential serious impact on the agricultural sector, such as the recent Ebola virus disease (EVD) outbreak in West Africa, there is a need during the epidemic to provide an accurate ex-ante assessment of the impact of the outbreak on agriculture, livelihoods and food security, to support the design of effective emergency relief and rehabilitation programmes to minimize the impact of the outbreak on affected populations. However, assessing the impact of EID outbreaks such as Ebola on agriculture is challenging because the disease restricts access to farms and households, limiting the possibility to conduct direct measurements and carrying out interviews.

The purpose of this article is to outline a methodology for assessing the impact of Ebola on agricultural production. Asimulation model, the Disease Impact on Agriculture – Simulation (DIAS) model was used during the last Ebola outbreak in West Africa to quantify its impact on cereal production in Guinea, Liberia and Sierra-Leone. A limited amount of field survey information, where available, was used to fine tune and improve the model accuracy.

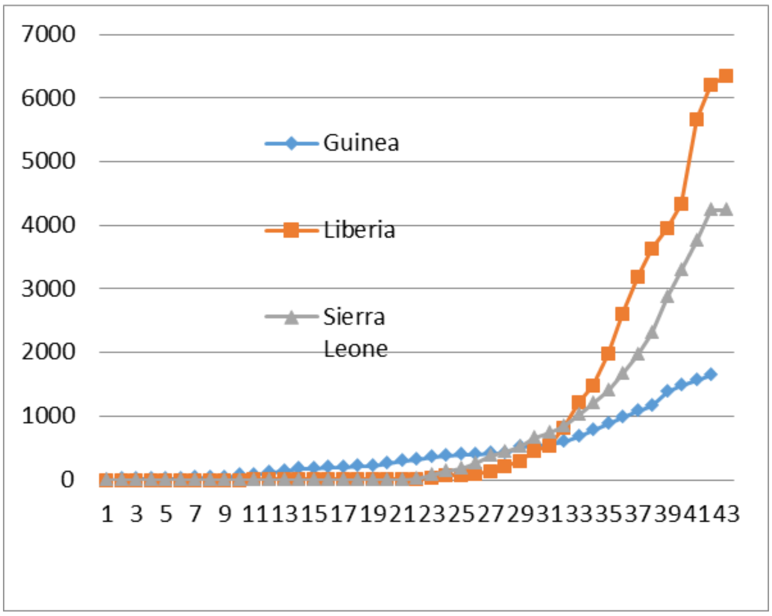
The reminder of paper is organized as follows: section 2sets out the channel of impact of EVD on agricultural production; section 3 outlines the methodology and the data used;section 4 presents and discusses the results. Finally, section 5summarizes the main conclusions.

2. Ebola virus disease (EVD) outbreak and agriculture

As outlined by the World Bank (2014), the impact of the Ebola epidemic on economic well-being operates through two distinct channels. First, there are the direct and indirect financial and human costs of the disease. Second, there are the behavioral effects resulting from peoples' fear of contagion, which leads to a series of disruptive actions and decisions by the population and public actors. These behavioral actions reduce labourforce participation and disrupt several economic sectors including transportation and trade. In the case of recent infectious disease outbreaks such as the SARS epidemic of 2002-2004 and the H1N1 flu epidemic of 2009, behavioral effects have been responsible for as much as 80 or 90 percent of the total economic impact of the epidemic (The World Bank 2014).

The last EVD outbreak in West Africa started in Guinea in December 2013, escalated the fastest in Liberia in early 2014 (see figure 1) and led to a sharp disruption of economic activities. The number of cases in Guinea were high during early part of the outbreak but remained relatively low during later part of the outbreak. In Liberia and Sierra Leone it led to the quarantining of the most affected regions, restrictions of internal population movement, as well as closure of markets. According to the figures from the World Health Organization (WHO), a total of 28 616 confirmed, probable and suspected cases were reported in Guinea, Liberia and Sierra Leone, with 11 310 deaths. The Public Health Emergency of International Concern (PHEIC) related to the outbreak was lifted in March 2016.

Figure1 : Evolution of the EVD crisis: number of cases as of December 2014



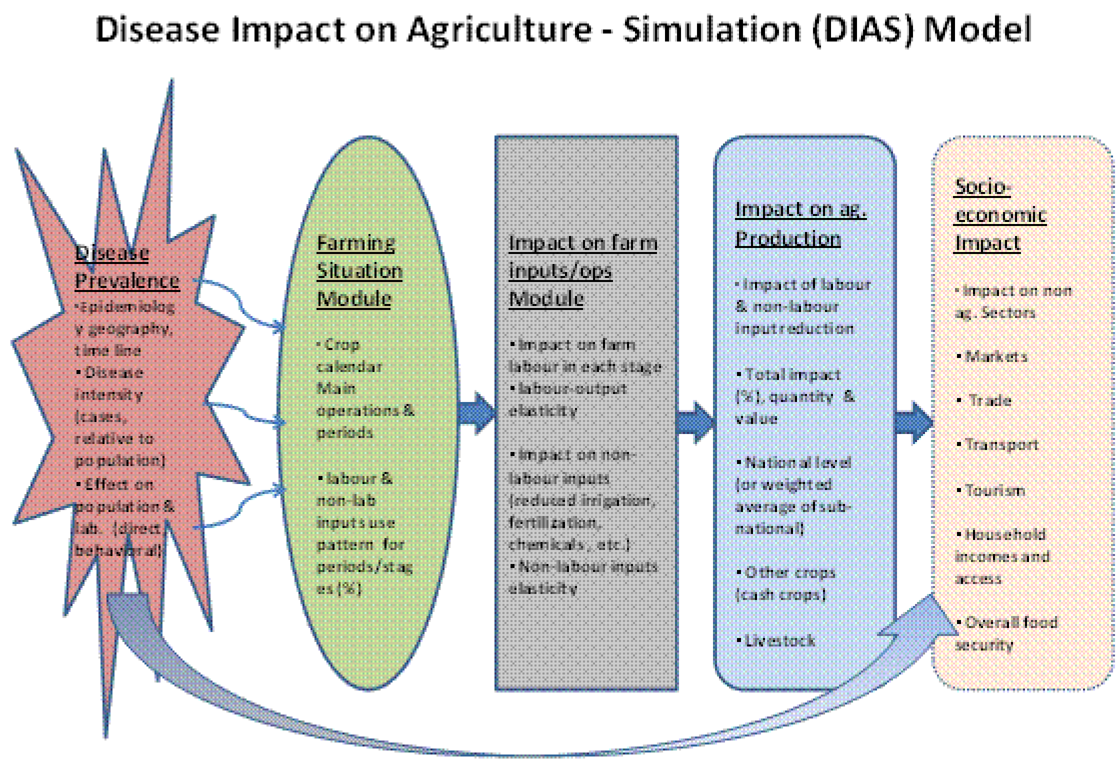
Rice is by far the most significant crop and it is grown on between 80-90 percent of all cereal-cropped area in the three most affected countries; it is virtually the only cereal grown in Liberia. Other food crops include cassava (in all three countries) and maize (in Liberia and Sierra Leone). In addition, the three countries grow cash crops, particularly cacao beans, coffee and rubber, which make up the bulk of their agricultural exports. In general, the EVD epidemic started to spread when crops were being planted and grew during the crop maintenance period, and then expanded rapidly during the critical harvesting period for the staple rice, maize and cassava crops.Farm operations, inputs and then harvestingwere affected in two ways. The main impact was seenthrough reduction in farm labour due mostly to aversion behaviors such as quarantines, border closures, restrictions/ban on people movement, people fleeing infected areas, reluctance to work in usual labour groups, etc. The disrupted/reduced farm labour affected land preparation/planting, crop maintenance/growth (weeding, fencing, application of chemicals, etc.), and harvesting. Secondly, through the labour associated non-labour inputs - reduced use of material inputs such as applied quantities of fertilizer, irrigation, chemicals, etc. Depending on their use and the relative impact these changes affect crop output.

3. Simulating the impact of EVD on crop production: the EVD Disease Impact on Agriculture – Simulation (DIAS) Model.

Quantitatively, the direct impact in terms of the number people infected in relation to the size of the population of the area is extremely small. Much of the impact observed has been of the behavioural type. The development of the DIAS model includes the following steps: (i) converting the relative cases of EVD infection into the impact on farm labour using a logistic function representing the S-Curve, (ii) assigning the labor use pattern and the labour associated non-labor inputs use pattern to each of the three major periods of crop production, (iii) establishingthe elasticity of labour and non-labor inputs and (iv) aggregating the impact of labor and non-labor input changes over different periods of crop production.

The most important component of the methodology is the use of the S-curve to quantify the impact of EVD on farm labour.

Figure 2: Schematic of EVD Impact on Agricultural Production Simulation



3.1. Using a logistic function (S curve) to calculate percentages of impact

Using a logistic function representing the S-Curve, the actual cases per 100 000 were converted to a percentage of population (and thereby farm labour) that may be considered affected. This follows a logic that as the number of cases of infection rise the impact is low at low number of cases but rises rapidly and then flattens out at some point. The formula adapted here is the following[1]:

$I = f(X) = S/(1+K\char`^(T+V/2-X)/V))$

Where,

I = the percent impact on population (and by extension on labour) for a given value of X.

X = Variable X represents the number of relative cases of Ebola disease, for example per 100 000 of population.

S = Saturation point (maximum potential impact in % of labour disrupted completely, asymptotic limit of the S curve). An arbitrarily chosen value of 1/3 (or 33%) is used here.

[1] Modified from the following presentation of the S-curve: https://akapps.wordpress.com/2011/08/27/simple-s-curve/

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Past studies on HIV infection rates have shown that the saturation points occurred at 39% for Botswana, 33.4 % for Swaziland and 31 % for Lesotho(see Whiteside & Erskine, 2002). A mobile phone survey carried out by the World Bank, with the Liberian Institute of Statistics and Geo-Information Services and the Gallup Organization, in October and November 2014, concluded that " ... 30 percent of respondents indicated that they were no longer working in agriculture compared to the baseline HIES. The majority cited worries about Ebola as the main reason they were not working.".

K = A <u>constant</u> used as a base for the exponential calculations (similar to log to the base 10 or the natural log to base e). It is set equal to 81 as in the original market study. In general, the smaller value of this constant, flatter the s-curve.

T = <u>takeoff point</u>; where on a severity scale of the infections the hyper growth in impact starts. The relative cases of infection at which the curve takes off and rises rapidly. The arbitrarily chosen value of 5 implies that when 500 cases are reported in a nation of 10 million people it will start having a significant general panic and the behavioral impact on population.

V = <u>takeover level</u>; it represents the number of relative cases when almost 90% of the impact is felt, for example at 100 in this case. Thus the steep rise of the curve is experienced between 5 and 100 relative cases.

Labour requirement varies depending on crop development stages. Rice being the predominant crop, the rice crop calendar was used as the main agricultural calendar. To accurately assess the impact of labour shortages at three different crop development stages, the crop calendar that covers about 9 months, was divided into three 3-month periods corresponding to land preparation/planting, growing/maintenance and harvesting in accordance to FAO/GIEWS crop calendar.

Figure 3: FAO/GIEWS average food crop calendar

WFP-compiled WHO data was used to input the cumulative cases. The first cases of EVD were reported in Guinea and Liberia in March 2014 and in Sierra-Leone in May 2014, but Liberia has been the hardest hit country (see figure 1). In Liberia, the incidence was later but steeper, affecting rice growing (labour and other inputs) and harvesting period; In Guinea, cases remained low through growing and harvesting period. Assuming a certain incubation period length of the EVD, the representative cases for each period were taken from the end of that period, i.e. the cumulative number of cases as of the last week in June, September and December for the three periods, respectively. To get the relative impact of the disease, the cases were expressed as per 100,000 people.

3.2. Assigning the labor use pattern to each period of crop production and simulating the impact of labor use reduction

Elasticities are important assumptions that affect simulation results.Hence, the second most critical set of information is about farm input elasticies and input use patterns. Based on relevant literature for various countries of West Africa (Olumbanjo, O and Oyebano, 2005; Kapsos, 2005; Vollrath D, 2009; Olujenyo, 2004), the labor elasticity for rice was set at 0.5 for the three countries.Labour elasticities for maize and cassava were set at 0.47 and 0.3, respectively.

According to Ngeleza et al (2011), the labor use pattern for rice is as follows: 38% of labour is used during land preparation and planting; 38% used during crop growth and 23% in harvesting. Requirement for cassava is typically 28% , 46% and 26% for these respective crop cycle periods. Using these rates of monthly labour use per operation, total labour use per three-month period from April-December was calculated. The labor use pattern for Maize is 59% 35% and 6% respectively.

In addition, the reduction in farm labour would also reduce the use of other non-labour material inputs such as fertilizer, chemicals, irrigation, etc. It is assumed that non-labor inputs such as fertilizer, other chemicals, irrigation etc. are applied during planting and crop growth periodsfor rice and maize. Thus weights of 50:50:0 areselected for the three periods as the pattern of their use during these three periods. Cassava production does not involve much use of these other inputs, hence only labour impact is calculated.

For simplicity the model groups all inputs into two, labor and non-labor. Using the implicit constant unitary elasticity of production such as the one used in the Cobb-Douglas production function, the sum of all input elasticities is assumed to be equal to 1. Given that we already have the labor elasticity value, the non-labor elasticity is simply calculated as one minus the labor elasticity. The elasticity is then applied accordingly to step 6.

Finally the impact of reduction in labour and non-labour, is calculated using their use patter and elasticities and summed across the three periods to get the final impact on crop production.

4. Results

The impact of Ebola was simulated at county or district level for each country and then aggregated at national level. Table 1 shows the aggregated simulation results at country level. Detailed results atcounty or district levels are shown in annex. As expected, rice was the most affected commodity due to its higher labour and inputs requirement. However, the impact on production was not as catastrophic as envisaged at the time of the outbreak. In Liberia, the most severely affected country, rice production is estimated to have declined by 12 percent from the without Ebola scenario (see Table 1). Output dropped by 7 percent and 4 percent in

Sierra Leone and Guinea, respectively. The relatively high level of impact in Liberia as compared to the other two countries affected by EVD, namely Guinea and Sierra Leone, is primarily due to the much higher intensity of the disease transmission. The infections grew rapidly during the crop growth and harvesting periods of the crop cycle. The sub-national level impact is even much higher in the counties hit hard by the disease, such as Lofa and Margibi in Liberia, where losses of paddy crop are estimated in the order of 20 percent and three others, Bomi, Bong, Monte Serrado, above national average. The simulated impact on maize was lower: maize production was estimated to decline by 3 percent and 4 percent in Sierra-Leone and Guinea, respectively.

Similarly, cassava being much less labour and input intensive crop than cereals, the impact on its harvest is estimated to be lower at 5 percent and 1 percent at the national level in Liberia and Guinea, respectively. In Liberia, cassava losses ranged from 1 percent in Grand Gadeh county to over 7 percent in Lofa and Margibi counties. It should be noted, however, that cassava roots can remain under ground and can be harvested as and when needed, hence the reduced harvest this year should not, necessarily be equated with the potential production of the commodity.

Table1: simulation results:

Country	Simulation Model
	Rice
Guinea	-4%
Liberia	-12%
Sierra Leone	-7%
	Maize
Guinea	-3%
Sierra Leone	-4.2%
	Cassava
Guinea	-1%
Liberia	-5%

In parallel to the modelling exercise, FAO and WFP, in collaboration with the Governmentsof Liberia, Guinea and Sierra-Leoneand other partners have carried out field level rapid assessments (RA) including surveys using questionnaires to analyse the impact of the EVD crisis on food production, supply situation and the overall food security. Results from theserapid assessments have largely confirmed the simulation results: For example, results from the Liberian field assessment indicated that rice production would decline by 10-15 percent at national level and up to 25 percent in hardest hit regions. Similarly, field assessments conducted in Guinea estimated a 3.4 percent decline in maize production and a 1 percent drop in maize harvest.

Other economic indicators confirmed that the impact of the EVD outbreak on national food harvest was not catastrophic. For example, price of imported and local food prices remained mostly stable at relatively low levels in all three countries, indicating that supplies were adequate.

The model produces results of with Ebola situation compared to without Ebola situation. These estimates are useful to indicate the extent of potential losses of agricultural production due to the crisis and can serve as a guide for the type of and the areas for response interventions.

5. Conclusions

The analysis presented in this paper suggests that the impact of of EVD on the 2014 agricultural production was moderateat the national level. However,the relatively low level of impact at the national level masks the subnational production and food security impacts. Moreover, beyond its impact on the agriculture and food sector, the EVD has seriously affected all other sectors of the economy with serious implications for household food security in the main affected areas. The mining, manufacturing and service sectors have been the hardest hit. According to the Economic Intelligence Unit (EIU), Sierra Leone's real GDP grew by just 4.6 percent in 2014, compared to 20.9 percent in 2013 before the EVD. In 2015, the effects of the EVD epidemic resulted in a sharp decline of 25 percent. With the EVD largely under control, real GDP is predicted to grow by 1 percent in 2016. Similarly,in Liberia, GDP growth is estimated at 0.9 percent in 2015, owing to the low output for Liberia's main exports and reduced harvests in 2014. A stronger rebound of 4.8 percent growth is forecast in 2016, well above the growth of only 0.5 percent achieved in 2014, but still well below the 6.8 percent forecasted before the Ebola crisis. In all three affected countries, the disruption of food chains due to the closing of markets, road blocks and quarantines, restricted cross border trading, as well as changes in traders' behaviour due to the fear of Ebola, has significantly reduced the income of EVD-affected communities including producers, consumers and traders. Specifically, income generating activities typically led by women, such as small trading, have been hit hard and the ban on bush meat has also deprived many households of an important source of nutrition and income. This has, in turn, negatively impacted on the food security situation of large numbers of people in the affected countries. Overall, about 2.2 million people, including 395 000 in Guinea, 720 000 in Liberia and 1.1 million in Sierra Leone, were estimated to be in need of urgent assistance due to the EVD crisis.

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Annex: - Impact of Ebola on 2014 crop production (tonnes)

Guinea

County	2013 Production	Simulation Model Result	2014 Production estimate
	Rice (Paddy)		
Boke	288,942	-3.1%	279,877
Faranah	306,106	-3.1%	296,602
Kankan	442,933	-3.2%	428,862
Kindia	332,193	-3.4%	320,809
Labe	115,102	0.0%	115,102
Mamou	108,407	-3.1%	105,040
Nzerekore	459,677	-8.4%	421,222
National Production	2,053,359	-3.7%	1,976,754
	Cassava		
Boke	77,841	-0.9%	77,109
Faranah	51,337	-0.9%	50,859
Kankan	347,543	-1.0%	344,235
Kindia	156,322	-1.1%	154,635
Labe	206,686	0.0%	206,686
Mamou	174,517	-0.9%	172,869
Nzerekore	204,678	-2.9%	198,779
National Production	1,218,925	-1.2%	1,204,805
	Maize		
Boke	67,993	-3.1%	65,863
Faranah	78,014	-3.1%	75,617
Kankan	137,284	-3.1%	133,001
Kindia	59,330	-3.3%	57,362
Labe	177,818	0.0%	177,818
Mamou	68,642	-3.1%	66,526
Nzerekore	83,164	-7.3%	77,056
National Production	672,244	-3.5%	648,742

Sierra Leone

	2013 Production	Simulation Model	2014 Production estimate (t)
Rice (Paddy)	1,255,559	-8.0%	1,155,114
Cassava	3,810,418	-3.0%	3,696,105
Maize	40,022	-4.0%	38,421
Sorghum, Millets, other cereals	102,300	-4.0%	98,208

Liberia

County	2012 Production (t)	Simulation Model	2014 Production estimate (t)
	Rice (Paddy)		
Bomi	7,570	-12.0%	6,661
Bong	62,370	-12.8%	54,372
Gbarpolu	16,140	-3.4%	15,588
Grand Bassa	15,500	-7.6%	14,329
Grand Cape Mount	9,140	-4.4%	8,741
Grand Gedeh	13,000	-3.1%	12,601
Grand Kru	10,420	-6.2%	9,771
Lofa	52,660	-20.0%	42,130
Margibi	7,710	-19.6%	6,203
Maryland	9,200	-3.2%	8,906
Monteserrado	7,570	-16.8%	6,295
Nimba	63,080	-7.8%	58,188
River Ghee	5,230	-5.6%	4,939
River Cess	9,100	-5.2%	8,623
Sinoe	8,500	-3.9%	8,165
National Production	297,190	-11.6%	262,570
	Cassava		
Bomi	14,530	-4.9%	13,818
Bong	71,660	-4.7%	68,263
Gbarpolu	14,050	-1.1%	13,901
Grand Bassa	37,080	-3.1%	35,949
Grand Cape Mount	17,910	-1.5%	17,642
Grand Gedeh	20,400	-0.9%	20,210
Grand Kru	28,500	-2.0%	27,920
Lofa	39,300	-7.3%	36,422
Margibi	21,440	-7.3%	19,870
Maryland	32,450	-1.0%	32,133
Monteserrado	21,440	-6.5%	20,056
Nimba	103,860	-3.2%	100,582
River Ghee	20,340	-2.4%	19,862
River Cess	20,500	-2.3%	20,037
Sinoe	21,730	-1.3%	21,438
National Production	485,190	-4.7%	462,584