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Full Length Research Paper

Economic benefits of biological control of cassava green mite (CGM) in Ghana

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The aim of the study was to evaluate the economic impact of biological control of cassava green mite (CGM) in Ghana by using the natural enemy *Typhlodromalus manihoti*. Both primary and secondary data were used for analysis. In total, 714 cassava producing households were drawn from 17 districts in seven regions of Ghana by employing a combination of proportional, purposive, simple random, and systematic random sampling techniques. Formal interviews with the use of standardized structured questionnaire were combined with field/farm visits to elicit information for the study. The 'with and without' comparison and trend analysis of secondary data were performed to evaluate project impact. The economic surplus model was used to estimate net benefits of biological control of CGM in Ghana in terms of Benefit-Cost Ratio (BCR), Net Present Value (NPV) and Internal Rate of Return (IRR). Following the release of about 2,344,817 CGM predators (*T. manihoti*) in seven regions of Ghana between the year 2007 and 2012, the study found evidence of *T. manihoti* presence in beneficiary communities. However, the level of establishment and extent of spread were markedly different across regions and districts in Ghana. The CGM biological control project in Ghana was found to have been successful in reducing CGM populations on cassava fields, reducing cassava root losses, improving productivity and profitability under varying climatic conditions and soil types. Biological control of CGM leads to higher economic gain to farmers and the country as a whole. Biological control of CGM was found to generate economic returns (NPV) of US$228.5 million, a BCR of 5,393.74 and an IRR of 3,424% at a discount rate of 20% for the period 2006 to 2046. Sensitivity analysis showed that the returns are robust even at higher discount rate (50%) and under pessimistic assumptions about yield gains. The overall project impact is expected to be higher when benefits to ecological and human health, which are usually difficult to quantify, are considered. Periodic inoculation in released communities and fresh releases in new communities are recommended if the country is to realize the full benefits of biological control of CGM.

Key word: Biological control, cassava green mite, economic gain, impact, *Typhlodromalus manihoti*.

INTRODUCTION

After many years of neglect as a poor man's crop, cassava has emerged as a dominant staple food crop of primary and secondary importance in many developing countries. Owing to its ability to withstand drought and thrive well on poor or marginal soils, cassava is a key nutritionally strategic famine reserve crop in areas of unreliable rainfall (Kleih et al., 2013; Hendershot, 2004). The crop can remain in the ground for up to 18 months or more after maturity. Cassava contributes about 22% to Agricultural Gross Domestic Product in Ghana (Lam, 2012; FAO, 2000). Cassava has edible starchy, tuberous root which is a major source of carbohydrates for the majority of people in regions where it is cultivated. It ranks third as a source of food calories in tropical countries after rice and maize (UNCTAD, 2014).

Apart from Upper East and Upper West Regions, the crop is cultivated in all regions of Ghana by over 90% of Ghana's farming population (FAO, 2005). Cassava is consumed by almost all households in Ghana and it accounts for a daily calorie intake of between 20 and 30% in the country (Angelucci, 2013; FAO, 2000; World Bank, 2010; Quiñones and Diao, 2011). The per capita consumption of cassava in Ghana is estimated at 152.9 kg/year. In terms of calories, cassava consumption per day per person in the country was reported to be 599 kcal by Angelucci (2013). The leaves of cassava have adequate amount of dietary proteins and Vitamin-K (FAO, 2005).

The role of cassava as food security crop in Ghana is threatened by many constraints, key among which are disease and pest infestation. Diseases and pests can cause yield losses up to 90% in most cassava growing areas where susceptible varieties are very common. Cassava Green Mite (CGM), *Mononychellus tanajoa,* is one of the most important pests contributing to damage and losses in cassava production (Évila et al., 2012). The CGM got introduced to Africa accidentally from South America in the early 1970s and has spread to all cassava growing areas in Africa (Yaninek, 1994). Its development occurs in about 10 days and a female can live up to 30 days and lay more than 60 eggs during her life time. Peak CGM densities occur during the first half of the dry season, with a smaller peak occurring within a month of the start of the long rainy season. Apart from the egg, which is inactive, there are four active stages including *larva*, *protonymph*, *deutonymph* and *adult* male and female. These active stages feed on the bottom surface of cassava leaves by sucking fluids from cells. This causes yellow spotting of leaves (*chlorosis*), which can increase from a few spots to complete loss of chlorophyll (Markham et al., 1987). Cassava green mites are generally found on the upper third of the cassava plant. Leaves damaged by CGM may also show mottled symptoms which can confuse it with symptoms of cassava mosaic virus disease (CMD). Severely damaged leaves dry out and fall off, which can cause a characteristic candle stick appearance. Because of reduced plant growth, accumulation of starch in the storage roots is slowed, sometimes even reversed, and root yield losses in the absence of any control measures can reach 50% (Hui et al., 2012). Where leaves are eaten as vegetables by farmers, a corresponding loss of leaves is recorded. Reduced growth and stunting of the tips are also responsible for contorted and thin stems, which affect the planting material to be used for the next season.

Yield losses of between 10 and 80% have been reported from agronomic trials in Africa. In a coordinated regional trial to estimate yield loss from CGM using standardized methods, average losses of 10 to 30% were recorded 12 months after planting in seven eastern and southern African countries. Losses were greatest where the dry season was longest and less severe where the dry season was shortest (Markham et al., 1987). Heavily attacked leaves are stunted and become deformed as they mature and tuber yields could be reduced by at least 30% under the best planting conditions (Megevand et al., 1987). The density of CGM population (and hence yield losses), is generally influenced by several factors including: age of the host plant (young plants are more exposed and susceptible than older plants); season (damage severity is greater during dry than wet season, and heavy rainfall can reduce CGM populations); temperature (populations increase with increasing temperature leading at times to very rapid increase in populations and damage); and poor agronomic practices (plants grown on poor soils are more susceptible to mite attacks) (Yaninek, 1994).

Several attempts have been made to control CGM in the past. Initial efforts to control CGM relied mainly upon the use of chemical sprays and cultural practices, and to a lesser extent, on host plant resistance. Since cassava varieties respond differently to CGM attacks, genetic improvements have also been tried to improve resistance. However, breeding for resistant varieties can take a very long time. Chemical control measures are also possible but with several adverse effects. Although several insecticides and miticides (such as *Dimethoate* and *Dicofol*) can control CGM, they are often too expensive for farmers and may be dangerous if not well applied, especially in countries where leaves are consumed as vegetables. Chemicals also have serious adverse effects on proliferation of beneficial soil microorganisms, the environment in general and human health. Several cultural methods, such as adjusting planting time for the crop to escape severe damage at young age, mixing varieties to avoid genetic uniformity, and removing infested tips have been tried but without much success, primarily because these practices were not well suited for traditional farming systems (Yaninek, 1994).

After many years without effective control, other alternatives were explored. The experiences gained from the control of the cassava mealybug and the exotic

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nature of both the pest and cassava suggested that classical biological control could be a possible solution. The biological control involved the use of CGM's natural enemies from South America where it originated. Several predatory mites of the family Phytoseiidae that generally keep the mites under control in South America were introduced into Africa to try their efficacy. Three predators from Brazil, *Neoseiulus idaeus*, *Typhlodromalus manihoti* and *Typhlodromalus aripo* showed some promise in several countries where they were introduced. Of the three predators, *T. aripo* is the most widely distributed and in the year 2000, populations were introduced in Mozambique. However, *T. manihoti* (Tm) was introduced in Ghana, Benin and Nigeria. Field results have shown that where *T. aripo* has been present for three or more years, it can reduce CGM by an average of 50% and increase root yield by an average of 30%. *T. manihoti* can reduce CGM populations by half, but effects on cassava yield have not been rigorously determined. Evidence also suggests that CGM control is greater where both *T. aripo* and *T. manihoti* are present together (Coulibaly et al., 2004).

Since 1989, Ghana has depended on *T*. *manihoti* as the appropriate biological control measure against CGM. Since 2007, the Ministry of Food and Agriculture through Root and Tuber Improvement and Marketing Pogramme (RTIMP) has introduced populations of *T. manihoti* in seven cassava growing regions in Ghana to help control CGM. Having employed this biological control method for over five years now, an evaluation of economic impact was imperative.

Therefore, the purpose of this study was to assess the economic impact of the release of *T. manihoti* in the control of CGM in Ghana. Specific objectives of the study were to:

(1) Determine the extent of spread and establishment of *T. manihoti* in major cassava producing communities closer to locations of releases;
(2) Assess the level of abated losses due to the biological control measure
(3) Evaluate the economic gains associated with biological control of CGM in Ghana.

METHODOLOGY

The study used both primary and secondary data for analysis. Secondary data was obtained from the Ministry of Food and Agriculture, whilst primary data was obtained from cassava farming households in all the seven regions that benefited from the biological control (*T. manihoti*) project. Districts, communities and farming households in these regions were selected through a multi-stage sampling approach. A combination of proportional, simple random, and systematic random sampling techniques was adopted to select the sample.

In all, seventeen districts were selected from the list of targeted regions based on the number of districts that benefited from the project. A total of five out of the 13 beneficiary districts in the Eastern Region were selected; three districts each were selected from the Ashanti and Central Regions; and two districts each from Volta and Brong-Ahafo Regions. In the Greater Accra and Western Regions, one district each was selected. The population of *T. manihoti* released and the history of the district with regards to project implementation as well as geographic representation informed the selection of districts (Table 1). For each district selected, a total of six communities (3 beneficiary and 3 non-beneficiary/control communities) were selected through purposive and simple random sampling techniques by using a sampling frame provided by RTIMP (the project implementing Agency). Control communities were selected carefully to ensure that soil characteristics, agricultural production systems and climatic conditions were similar to those found in project beneficiary communities.

In each of the selected communities, a total of seven cassava producing households were selected using systematic random sampling method. In total, a sample size of 714 cassava producers were drawn from the population and interviewed using a standardized structured questionnaire. Key informants were also interviewed using a checklist. In addition, farm visits were conducted for spot observation of *T. manihoti* and CGM. During these farm visits, diagonal transect walks through cassava fields were done to sample 30 plants for close observation using magnifying lenses to do predator-prey counts. Wherever *T. manihoti* was observed, the team travelled at least 10 km to the north and south or east and west of the farm depending on where the available road/path was leading. This was to establish the extent of natural spread of *T. manihoti* from the point of release.

A combination of descriptive and inferential tools was employed to analyze field data. Frequency distribution tables, graphs, arithmetic mean and standard deviation were used to summarize responses obtained from farmers. Largely, for the impact analysis 'with and without' comparison and trend analysis were performed. The student's t-test was employed to test for differences in certain parameters (yield level, level of damage, gross margins, net returns, and returns on investment) between control and treatment groups. The 'before and after' comparison was not employed due to the long recall period which made production information before the start of the project largely unreliable. This problem was compounded by the fact that farmers did not know about the release of the predator, *T. manihoti,* in their respective communities.

Secondary data on cassava production, acreage cultivated and yields for the selected regions and the country as a whole before and after the release of the predator (biological agent) were obtained for comparative trend analysis using line graphs.

Economic surplus models are commonly used to assess the impact and distributional effects of a technology or research activity (Wander et al., 2004; Alston et al., 1995). Assuming market equilibrium, the impact of the biological control of CGM can be assessed through yield increases. The net gain is the difference between the increased production value and the costs of research and extension associated with the biological control. Coulibaly et al. (2004) used the economic surplus model to estimate the net benefits of the biological control of CGM to Bénin, Ghana, and Nigeria in terms of Net Present Values (NPV) and Internal Rate of Return (IRR). The NPVs were computed as the difference between the projected discounted benefits and discounted costs over the period 1983 (beginning of research on biological control of CGM) to 2020.

A similar approach was adopted in this study to evaluate the economic benefits of the release of *T. manihoti* to the country as a whole. Costs and revenue streams were discounted at a rate of 20%, which is commonly used in long-term social/development projects (15 to 20 years) in developing countries (Oleke et al., 2013). The following formulae were adopted to estimate the Benefit-Cost Ratio (BCR), Net Present Value (NPV) and IRR of the project in Microsoft Excel spreadsheet.

Table 1. Summary of sampling strategy.

Target region	Selected districts	Sample size
1.Ashanti Region	Mampong	42
	Obuasi	42
	Asante-Akim South	42
2. Eastern Region	West Akim	42
	Akuapim South	42
	Suhum-Kraboa-Koaltar	42
	Birim Central	42
	Fanteakwa	42
3. Central Region	Abura-Asebu-Kwamankese	42
	Gomoa West	42
	Twifo-Heman-Lower Denkyira	42
4. Brong/Ahafo Region	Brekum	42
	Techiman	42
5. Volta Region	Hohoe	42
	South Tongu	42
6. Gt. Accra Region	Ga West	42
7. Western Region	1Ahanta West	42
Total		714

$$\mathrm{BCR} = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t} \Big/ \sum_{t=1}^{n} \frac{C_t}{(1+r)^t}$$

$$\mathrm{NPV} = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t}$$

The IRR is the discount rate (r) in the following expression that equates a time series of benefits and costs.

$$\sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t} = 0$$

where B_t = Benefit in each year, C_t = Cost in each year, t = number of years/economic life of the project (t = 1, 2,…n), and r = interest (discount) rate.

RESULTS AND DISCUSSION

Characteristics of respondents

Table 2 shows that cassava farmers interviewed in treatment and control communities were similar in characteristics. They were all within the economically active age group (48 years), had large household size (7 persons), and had been involved in cassava farming for almost 20 years. However, years of formal education and total agricultural land owned by a typical household were significantly higher in treatment communities than in control communities. Student t-test analysis showed that cassava producers across different regions were significantly different in age, education level, farming experience, and household land holdings at the 1% level. However, household sizes were not statistically different across the seven regions surveyed.

Establishment and spread of the biological agent (*T. manihoti*)

From RTIMP reports, a total of 2,344,817 CGM predators (*T. manihoti*) were released in seven cassava producing regions in Ghana between 2007 and 2012 (Table 3). The distribution covered about 70 districts and an average of 23 communities or points of *T. manihoti* releases per year. The number of communities or points of releases ranged from a minimum of 14 in the year 2009 to a maximum of 103 in the year 2011. Ashanti, Eastern, Central and Brong-Ahafo Regions cumulatively received about 85% of the total releases during the period under

Table 2. Descriptive statistics for control and beneficiary farmers.

Variable	Test/Beneficiary	Control	Pooled sample
Age of respondent (years)	47.8395	47.4861	47.6631
Years of formal education**	8.7361	8.0364	8.3943
Household size	6.5556	6.6471	6.6012
Years of farming	22.0233	21.9443	21.9837
Years of cassava farming	19.4151	19.7229	19.5688
Agric. land owned (acres)*	11.4286	8.586	9.9983

**Difference is significant at 5%; *Difference is significant at 10%. Source: Field survey, 2014.

Table 3. *T. manihoti* Releases across regions in Ghana (2007-2012).

Region	2007	2008	2009	2010	2011	2012	Total
Ashanti	152,796	134,794	113,250	-	164,500	68,000	633,340
Brong-Ahafo	17,521	-	40,000	95,000	201,100	50,000	403,621
Central	73,392	99,104	-	75,000	188,000	26,000	461,496
Eastern	14,583	198,800	-	159,000	103,500	22,000	497,883
Gt. Accra	-		-	-	56,500	-	56,500
Volta	-	76,158	-	82,100	11,200	-	169,458
Western	-		122,519	-	-	-	122,519
Total	258,292	508,856	275,769	411,100	724,800	166,000	2,344,817

Source: Extracted from RTIMP database, 2007-2012.

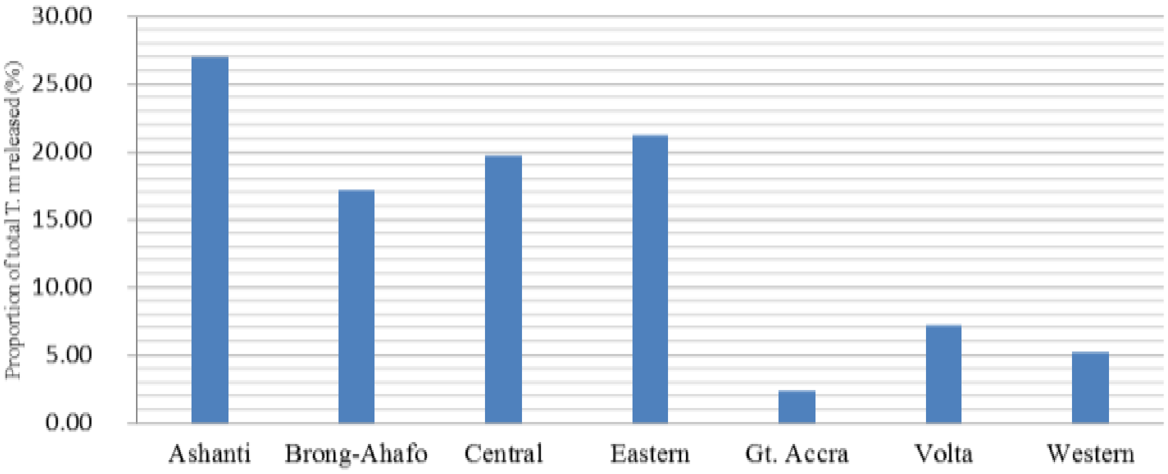

Figure 1. Regional distribution of cumulative *T. manihoti* releases in Ghana (2007-2012). Source: Generated from RTIMP database, 2007-2012.

review (Figure 1).

During field visits, there was evidence that T. manihoti had been released in most of the beneficiary communities. However, the level of establishment and extent of spread were markedly different across regions and districts in Ghana. Eastern, Ashanti and Brong-Ahafo Regions had relatively high rates of *T. manihoti* establishment and spread. The spread of *T. manihoti* from released areas in Central, Western and Volta Regions appeared to be very limited. In the Greater Accra region, there was generally no clear evidence of *T. manihoti* establishment. In *Amasaman* in the Ga West District for instance, cassava fields including those on which the *T. manihoti* was released were lost to sand winning. The population of CGM was generally low across the regions. Predator-prey ratios were very difficult to estimate for cassava fields visited in most of the regions since the population of either the predator or

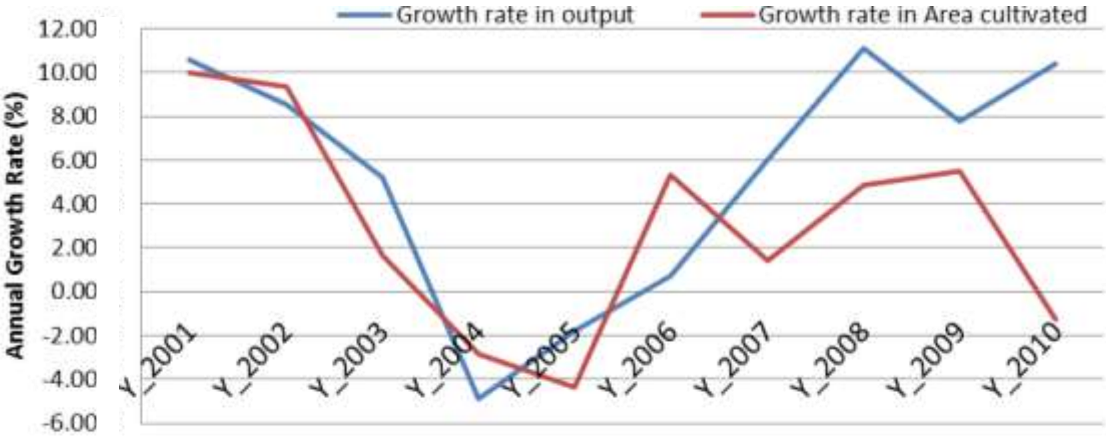

Figure 2. Annual Growth rate in area cultivated and cassava output in Ghana. Source: Generated from own calculations based on MoFA, 2011.

prey was zero. In our estimation, the absence of CGM and *T. manihoti* could be evidence that the predator suppressed the populations of the prey but could not survive due to starvation or effect of unfavourable environmental conditions. For example *T. manihoti* survival in the Western and Greater Accra regions appeared to have been adversely affected by environmental conditions especially high rainfall in the former and sand winning activities in certain parts of the latter. Ratio of *T. manihoti* to CGM could be approximated to range between 2 and 5 for some cassava fields in beneficiary communities in the Eastern Region. It was largely noticed that in communities where *T. manihoti* was observed, it had not spread beyond an average distance of 5.0 km from the point of release along the main/bush road close to the visited farm. The low *T. manihoti* populations found in many communities especially in the Western, Greater Accra, Volta and Central Regions suggest that periodic inoculative releases of the predator need to be undertaken to consistently keep the population of CGM under control.

Cassava production trend analysis

Trends in area put under cassava cultivation and national cassava production levels have followed a similar trend over the past decade. The two production indicators recorded increasing trends from 2000 to a peak in 2003 after which there was a decline with the lowest figures recorded in 2005. From 2005 to 2007, the growth rate in area cultivated and total output was quite slow. However, there has been an increasing trend in these indicators since 2007, the year the *T. manihoti* project commenced (Figure 2). A critical analysis of the growth rates indicates that before the *T. manihoti* project was implemented (2000 to 2006), area cultivated to cassava and total output grew by almost the same rate per annum (that is, 3.2 and 3.1%, respectively). However, after the implementation of the *T. manihoti* project (2007 to 2010), area cultivated to cassava grew at an annual rate of only 2.6% compared to output growth rate of 8.8% per annum during the same period. This finding suggests that at the national level, whereas cassava output growth reflected rate of expansion in cultivated area before the *T. manihoti* project, annual growth in cassava output is more than double the growth rate in land area cultivated to cassava after the *T. manihoti* project implementation. This implies that yield per hectare has improved significantly after the implementation of the biological control method (Figure 3). It is worthy of note that this observed improvement in overall production level and yield could be partly attributed to good agronomic practices and introduction of new technologies such as improved varieties of cassava during the period under review.

Cassava production information from 2009 to 2013 gathered from the field survey in treatment and control communities have been summarized in Table 4*a*. Total output of cassava harvested by a typical household was estimated at 6.24 MT per acre (52 bags) in 2009 and 6.72 MT per acre (56 bags) in 2013. Figures 4 and 5 provide yield trends and trends in cassava root losses across the seven study regions and also for treatment and control communities. There is a general increasing trend for cassava root output and a decreasing trend for cassava root losses in beneficiary communities. However, in control communities, the trends are not as pronounced even though they follow the same direction of movement. Cassava output has been increasing consistently in treatment communities just as they have been in control communities. However, in 2013 cassava output decreased in control communities but stayed the same in treatment communities. In the years 2009, 2012 and 2013, the level of cassava root losses recorded in treatment communities were significantly lower than in control communities at the 10% level. The *T. manihoti*

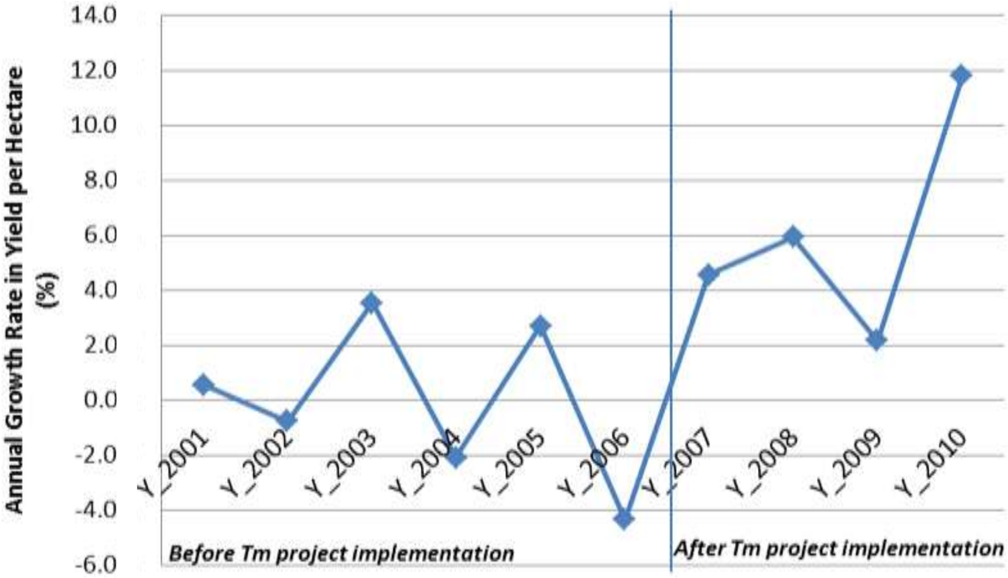

Figure 3. Annual Growth Rate in Cassava Yield in Ghana. Source: Generated from own computation based on MoFA, 2011.

releases could account for the reduction in root losses in treatment communities. Figure 5 shows that there has been a consistent decline in the proportion of cassava root losses in the surveyed communities since 2009 and the role played by the *T. manihoti* releases which commenced in 2007 in this effort cannot be down-played.

Profitability analysis

Figure 6 provides a summary of the profitability analysis for producing cassava in the seven different regions surveyed during the study. Detailed cost items are provided in Appendix 1. A typical cassava producer sampled incurred total variable costs of GHC649.39 and generated gross revenue of GHC877.33 per acre. This translates to a gross margin of GHC227.93 per acre. From the figure, it may be evident that producers in Greater Accra Region obtained the highest gross margin of about GHC533.82 per acre compared to those in Central Region who obtained only GHC117.86 per acre as gross margin. The net margin analysis revealed that cassava production in Central Region during the 2012 cropping season produced a very tight margin which is very close to the break-even point. Benefit-Cost Ratio for producers in this region was a little below unity (1), indicating that farmers barely generated enough returns to cover their investment costs. Cassava production was found to be most profitable in the Greater Accra Region, followed by Western and Brong-Ahafo Regions.

Figures 3 shows that profits associated with cassava production in treatment communities were significantly higher than in control communities during the 2012 cropping season at the 1% level. Critical analysis of profitability indicators reveal that gross margin per acre in treatment communities was about 66% higher than that obtained in control communities. In terms of net margin per acre, producers in treatment communities posted profit which was also about 151% higher than that obtained by farmers in control communities during the 2012 cropping season. However, cassava production was found to be profitable in both treatment and control communities since estimated Benefit-Cost Ratios (BCR) were above unity (1) in both community types. Returns on investment in cassava production in treatment communities (159%) were found to be more than double the level in control communities (68%).

Economic gains from biological control

Economic gain obtained by farmers from cassava production could be looked at as the additional benefits obtained as a result of the losses prevented (abated losses or loss reduction) between two production seasons. Table 5 provides the economic gain analysis for treatment and control communities. Quantities of cassava root losses avoided (saved) were significantly different between treatment and control communities for the periods 2009 to 2010 and 2011 to 2012. Producers in treatment communities saved larger quantities than those in control communities due to the lower level of damage recorded in treatment communities. The implication is that biological control of pest leads to higher economic gain to farmers, all other things being equal. In terms of monetary value, producers in treatment communities

Table 4. Profitability of cassava production in test and control communities (2012 cropping season).

A. Variable costs (all costs and revenues in GHC)	**Test**	**Control**	**Pooled sample**
Land clearing	216.5944	184.1212	200.1615
Land preparation	147.5789	134.5699	140.8011
Planting materials	195.047	176.0428	185.0998
Coppicing planting materials	60.1385	70.0578	65.4025
Carting planting materials (T&T)	53.0355	45.9326	49.3919
Planting cassava sticks	142.9191	127.6842	135.1239
First weeding	184.9751	162.6286	173.8217
Second weeding	170.3896	151.5664	160.8475
Herbicides (chemical weeding)	71.3593	67.1772	69.139
Herbicides application	45.5132	49.4361	47.6401
Costs of Insecticides	33.2759	45.36	38.8704
Insecticides application	34.7407	39.1875	36.8333
Total cost of knapsack rent	86.6629	73.4664	78.8271
Harvesting	62.9816	70.0556	66.5077
Gathering/heaping harvested cassava	168.433	126.7488	146.9152
Carting harvested produce to market/home (T&T)	15.6852	26.4237	21.292
Other variable costs	38.92	34.06	36.53
Total VC for whole farm	1878.25	1684.52	1779.20
Acres of cassava cultivated	2.728	2.7516	2.7398
Total Variable Costs per acre	688.51	612.20	649.39
B. Revenue			
Yield/acre (120kg bags)	22.13	19.43	20.76
Unit price (GHC)	44.1377	40.4492	42.2604
Gross revenue (B)	976.96	786.09	877.27
C. Gross margin (B-A)	288.45	173.90	227.88
D. Fixed cost			
Land rental	101.1	93.61	97.32
Cutlass/hoe	10.21	9.72	9.9623
Total fixed cost (D)	111.31	103.33	107.28
E. Net Margin (C-D)	177.14	70.57	120.59
F. Total Cost (A+D)	799.82	715.53	756.67
G. BCR (B/F)	1.22	1.10	1.16
H. Returns on investment (E/D)	159.14%	68.29%	112.41%

Source: Computed from field data, 2014.

gained about GHC92.67 between 2009 to 2010 farming periods compared with GHC21.15 for those in control communities during the same period in nominal terms. Between 2011 and 2012 period too, the difference in nominal monetary values of the extra gain between beneficiary and control communities was statistically significant at the 1% level. For the pooled sample, a typical cassava farmer gained additional 6 bags (0.7 Mt) of cassava roots through reduction in losses. This translates to about GHC218.00 of additional income to the farmer over the 2009 to 2013 cropping period in nominal terms.

Economic gain in the form of cassava planting materials saved could not be quantified due to paucity of data. Farmers could not provide useful estimates to enable the approximation of the value of planting materials. This was largely due to their inability to identify CGM on the field. There are other economic and environmental benefits associated with the biological control of CGM which could also not be quantified. For example, farm households saved money they would have used to buy other staple foods like rice and maize if

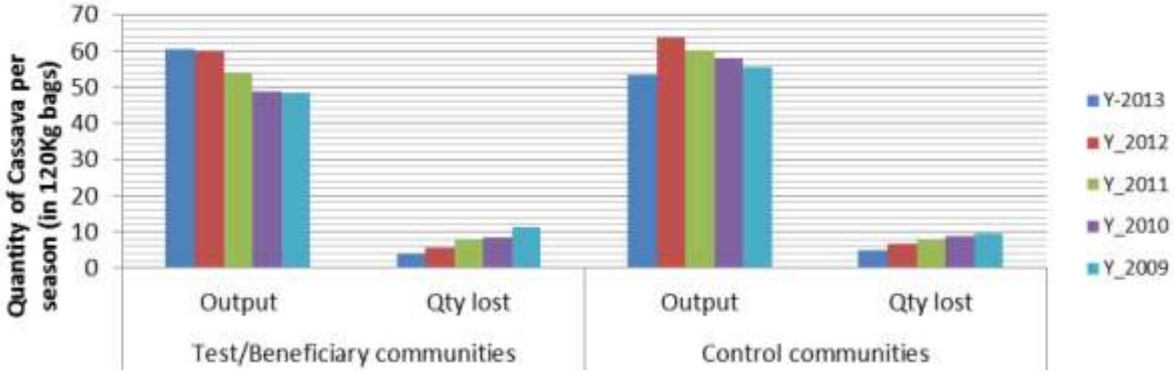

Figure 4. Cassava output and losses for beneficiary and control communities (2009 -2013 seasons). Source: Generated from field data, 2014.

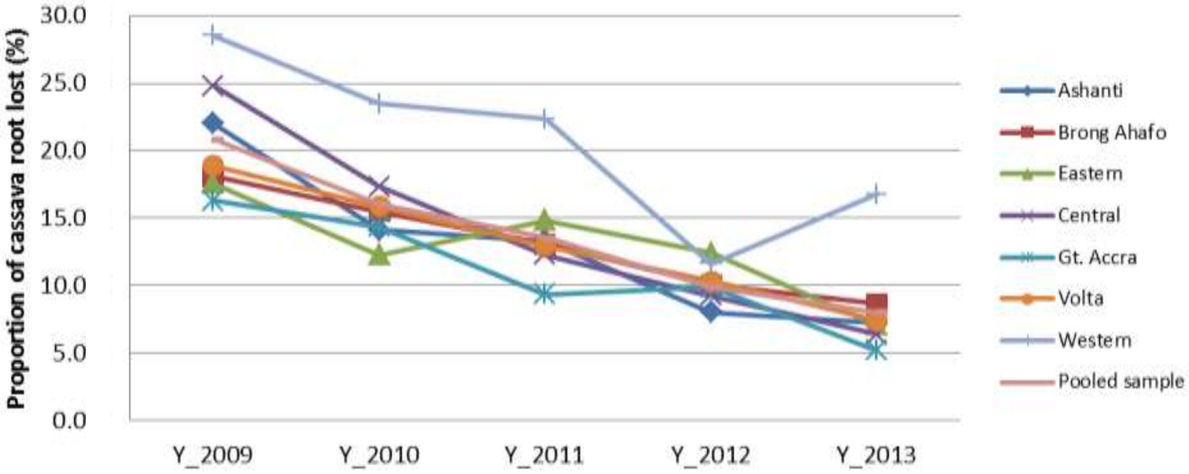

Figure 5. Trends in Cassava losses in the major producing regions (2009 -2013). Source: Generated from field data, 2014.

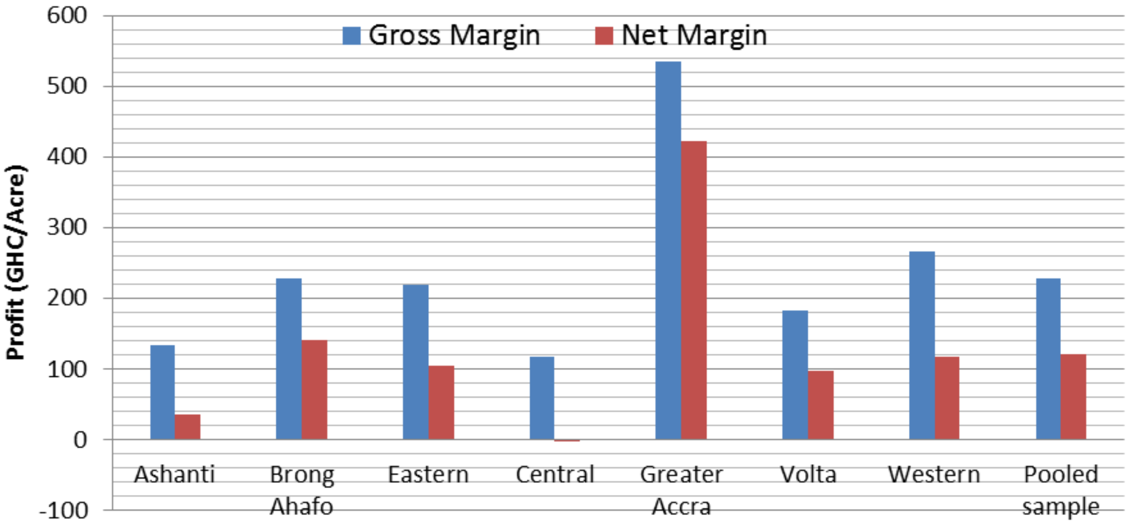

Figure 6. Summary of profitability analysis for cassava production across regions. Source: Generated from field data, 2014.

Table 5. Economic gain per farmer in treatment and control communities.

Year/Period	Test communities			Control communities		
	Q'ty of abated losses (120kg bag)	Unit Price (GHC)	Value of abated losses (GHC)	Q'ty of abated losses (120kg bag)	Unit Price (GHC)	Value of abated losses (GHC)
2009-2010	3.15	29.46	92.67	0.72	29.20	21.15
2010-2011	0.72	33.93	24.29	0.95	32.75	31.01
2011-2012	2.01	37.63	75.47	1.02	36.93	37.67
2012-2013	1.80	44.14	79.47	2.00	40.45	80.97

Source: Generated from Field data, 2014.

Table 6. *T. manihoti* project viability/economic benefit indicators.

Indicator	Discount rate (cost of funds)		
	20%	30%	50%
BCR	5,393.74	2,116.65	618.17
NPV (US$ million)	228.53	73.49	16.29
IRR (%)	3,424	3,424	3,424

Source: Generated from projected cash flow analysis.

Table 7. Results of sensitivity analysis based on *worst case scenario*[1].

Indicator	Discount Rate (cost of funds)		
	20%	30%	50%
BCR	3,445.89	1,389.68	409.54
NPV (US$ million)	145.99	48.24	10.78
IRR (%)	1,740	1,740	1,740

Source: Generated from projected cash flow analysis.

cassava root losses had increased as a result of CGM infestation. Ecological benefits in the form of forgone adverse effects of chemical residues (resulting from chemical pest control) on the environment and human life could be very substantial though difficult to quantify.

Biological control of pests is a long-term investment decision. Benefits associated with the *T. manihoti* releases will continue to accrue to the larger Ghanaian society over a long period of time in terms of abated root yield losses, reduction in planting material losses, enhanced household food and income security and environmental benefits in terms of ecosystem balance and adverse effects of chemical pests control that are avoided because of the project. Following standard investment appraisal techniques, the impact of the *T. manihoti* project was assessed by discounting the economic surplus derived from the project over a forty-year life span. This analysis was largely based on cassava root yield losses avoided/saved over the project life and the initial investment cost associated with importation of biological agent (*T. manihoti*) from South America, breeding and raising/multiplication of the predator and costs associated with releases and periodic monitoring of the bio-agent in cassava growing communities. Appendix 2 provides details of costs associated with *T. manihoti* releases in Ghana from 2008 to 2012 and the assumptions used for the projected cash flow analysis are provided in Appendix 3. Ignoring the value of planting materials and cassava leaves saved as a result of the *T. manihoti* releases and working with conservative figures on yield improvement and reduction in root losses, results from the investment appraisal show that biological control of CGM in Ghana has substantial economic returns (Tables 6 and 7). The estimated discounted economic returns (NPV) at a rate of 20% for the period 2006 to 2046 were found to be about

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[1] Percentage of yield losses saved was assumed to be 5% from 2007 to year4; from year5 to year10 this proportion was assumed to be 15% per annum and from year11 to the end of project life, losses saved were assumed to be 20% of total national output per annum.

US$228.5 million. The BCR of the project was 5,393.74 and its IRR or break-even discount rate was estimated at 3,424%. These indicators suggest that the *T. manihoti* project is a very beneficial public investment. Even at a high discount rate of 50%, the project produces NPV of US$16.3 million and BCR of 618.17.

At a discount rate of 10%, Coulibaly (2004) estimated NPV of about $383 million and IRR of 111% for CGM control in Ghana for the period 1983 to 2020.The figures obtained for Benin and Nigeria in the same study were $74 million (IRR=101%) and 1.7 billion (IRR=125%), respectively. Oleke et al. (2013) also evaluated the economic benefits of biological control of coconut mites in Benin and reported that in the least optimistic scenario, the economy of Benin would derive an overall net gain of US$155,213.40. At a discount rate of 12% for the period 2008 to 2027, the net present value and internal rate of return were estimated to be about $207,721 and 13.21%, respectively. Sensitivity analysis in the current study shows that returns to biological control of CGM in Ghana are still very substantial even under a higher discount rate of 50% and under lower yield gains (Table 7).

CONCLUSION AND POLICY IMPLICATIONS

The study concluded that the *T. manihoti* project has been largely successful in reducing CGM populations on cassava fields in the released areas in Ghana even though the role of the indigenous predatory mites cannot be underestimated. Findings from the study provide ample evidence to confirm the *a priori* expectation that biological control of the CGM is a viable technology. Economic returns from investing in the biological control of CGM in Ghana are highly significant and statistically different from zero. Sensitivity analysis showed that the results remain robust even when the discount rate is raised to 50% and when reduction in cassava root yield losses are assumed at conservative rates of less than 25%. Given that the study captured only conventional financial benefits of biological pest control, the overall impact is even expected to be higher when benefits to ecological and human health are considered. Results from the current study have, therefore, shown that classical biological control is a cost-effective and sustainable option to reduce crop losses due to pests under varying climatic and edaphic conditions in Ghana.

Since the natural ecosystem is dynamic and constantly changing, expected future benefits of the project can be realized if negative factors that may undermine the positive impacts of the project can be identified and addressed. It is recommended that contemporaneous with periodic inoculation in released areas and fresh releases in new communities, especially in Central, Western, Greater Accra and Volta Regions, plans should be underway to improve access to extension services especially on disease and pest control and capacity building for farmers to ensure that the full potential of the cassava crop is realized by the country. Also, knowledge and capacity for biological control of pest and diseases should be strengthened in Ghana since the country stands to gain immensely from it.

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Conflict of Interests

The authors have not declared any conflict of interests.

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Appendix 1. Profitability of cassava production across Regions for the 2012 cropping season.

A. Variable costs (All costs and revenues in GHC)	**Ashanti**	**Brong-Ahafo**	**Eastern**	**Central**	**Greater Accra**	**Volta**	**Western**	**Pooled sample**
Land clearing	207.29	300.68	185.57	158.42	224.16	179.84	108.13	200.16
Land preparation	151.60	274.86	104.74	108.26	183.87	127.73	121.00	140.80
Planting materials	156.11	224.05	182.80	297.76	194.95	148.24	72.29	185.10
Coppicing planting materials	47.32	66.69	69.57	154.45	48.73	41.65	51.65	65.40
Carting planting materials (T&T)	47.18	91.26	51.57	51.62	69.28	31.67	23.07	49.39
Planting cassava sticks	157.53	155.89	145.28	94.40	210.11	103.26	65.95	135.12
First weeding	197.63	255.83	174.41	98.68	214.11	152.07	44.40	173.82
Second weeding	171.13	209.59	171.74	91.14	215.42	151.42	38.89	160.85
Herbicides (chemical weeding)	55.27	81.29	81.99	64.48	61.08	57.14	71.89	69.14
Herbicides application	50.55	62.88	45.77	57.38	37.42	38.45	26.75	47.64
Insecticides	29.25	24.20	43.00	48.46	49.70	31.73	28.67	38.87
Insecticides application	23.75	39.20	31.25	50.14	38.33	32.33	27.00	36.83
Total cost of knapsack rent	8.11	7.24	21.20	39.04	14.53	13.37	82.78	21.29
Harvesting	219.01	339.90	263.46	104.06	162.16	113.23	55.40	204.83
Gathering/heaping harvested cassava	70.35	99.07	68.16	50.76	46.36	39.54	28.22	66.51
Carting harvested produce to market/home (T&T)	138.31	371.72	133.42	71.55	69.00	81.97	39.44	146.92
Other variable costs	40.93	45.00	32.10	22.00	50.00	47.92	0.00	36.53
Total VC for whole farm	1,771.33	2,649.35	1,806.01	1,562.58	1,889.19	1,391.57	885.53	1,779.20
Acres of cassava cultivated	2.15	3.90	2.66	3.42	2.97	2.39	1.31	2.74
Total Variable Costs per acre	823.72	679.53	679.57	457.16	635.30	583.03	676.29	649.39
B. Revenue								
Yield/acre (120kg bags)	23.72	33.08	24.43	12.47	23.26	17.1	14.68	20.76
Unit price (GHC)	40.3429	27.42	36.774	46.1121	50.2632	44.7885	64.2381	42.2604
Gross revenue (B)	956.93	907.05	898.39	575.02	1,169.12	765.88	943.02	877.33
C. Gross margin (B-A)	133.21	227.52	218.82	117.86	533.82	182.86	266.73	227.93
D. Fixed cost								
Land rental	87.99	77.58	105.57	111.63	101.94	74.81	140.40	97.32
Cutlass/hoe	9.9167	9.3354	9.8079	9.7768	10.2105	11.2636	8.8537	9.9623
Total fixed cost (D)	97.91	86.92	115.38	121.41	112.15	86.07	149.25	107.28
E. Net margin (C-D)	35.31	140.61	103.45	-3.55	421.67	96.78	117.48	120.65
F. Total cost (A+D)	921.63	766.44	794.94	578.57	747.45	669.10	825.54	756.67
G. BCR (B/F)	1.04	1.18	1.13	0.99	1.56	1.15	1.14	1.16
H. Returns on investment (E/D)	36.06%	161.78%	89.66%	-2.93%	375.99%	112.44%	78.71%	112.46%

Source: Computed from field data, 2014.

Appendix 2. Costs associated with releases of Tm in Ghana from 2007-2012.

S/N	Date	Amount (Gh¢)	Exchange Rate	Amount (USD)
	Year 2012			
1	8/6/2012	2839.20	1.9535	1453.39
2	2/14/2012	3340.80	1.7009	1964.14
	Total (2012)	-	-	3,417.53
	Year 2011			
3	6/22/2011	3072.00	1.5250	2014.43
4	3/23/2011	2000.00	1.5250	1311.48
5	2/25/2011	966.84	1.5150	638.18
6	1/18/2011	2778.72	1.4875	1868.05
	Total	-	-	5,832.13
	Year 2010			
7	10/5/2010	800.68	1.4225	562.87
8	5/5/2010	3331.00	1.4185	2348.26
	Total	-	-	2,911.12
	Year 2009			
9	10/22/2009	1924.00	1.4500	1326.90
10	7/7/2009	3216.00	1.4950	2151.17
	Total	-	-	3,478.07
	Year 2008			
11	12/17/2008	2000.00	1.2450	1606.43
12	7/14/2008	4000.00	1.1150	3587.44
13	2/8/2008	3500.00	1.0000	3500.00
	Total	-	-	8,693.87
Total	-	-	-	24,332.72
Average per year	-	-	-	4,866.54

Source: RTIMP, 2014.

Appendix 3. Assumptions underlying the projections used for investment appraisal

(a) Project life was assumed to be 40 years based on previous studies (Alene et al., 2006; Coulibaly, 2004; Oleke et al., 2013). Year 2006 was the investment period and project will last up to 2046.

(b) Actual cassava production figures from the seven project regions obtained from MoFA were used for the first 5 years (2006 to 2010); from years 6 to 10, output was increased by a constant rate of 8.8% per annum (calculated as an average growth rate in output for the period 2007 to 2010). After year 10, output was assumed to remain constant at the year 10 level for the remaining years of the project.

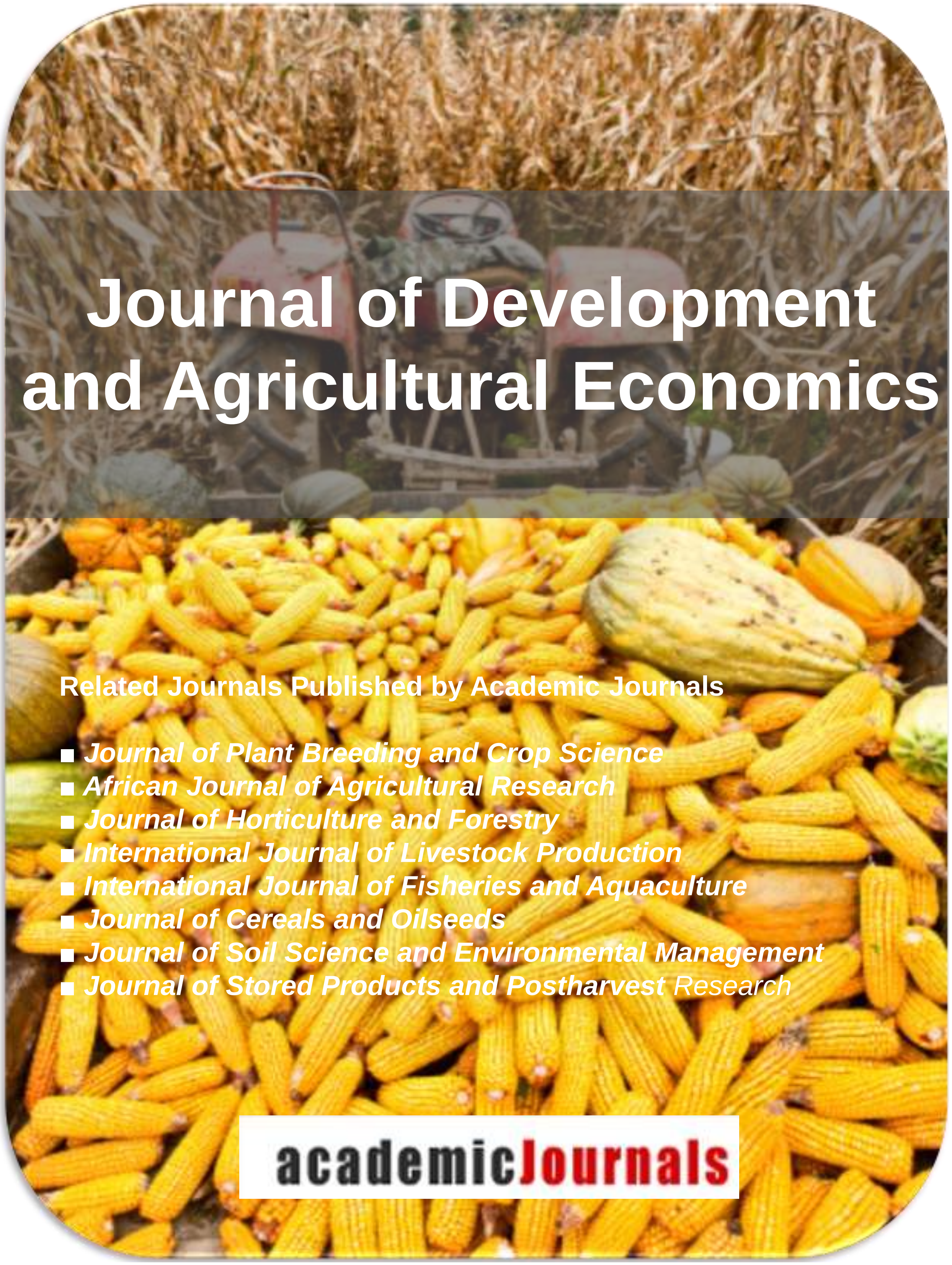
(c) Prices of cassava tubers/roots from 2006 to 2010 were obtained from MoFA records. From year 5 (2011) onwards, price of the crop in dollar equivalent was assumed to increase at a constant rate of 5% per annum.

(d) Percentage of yield losses avoided/saved as a result of the project was assumed to be 10% from 2007 to year 4 (2010); from years 5 to 10 this proportion was assumed to be 20% per annum and from year 11 to the end of project life, losses saved were assumed to be 25% of total national output per annum.

(e) Proportion of cassava acreage/land covered by *T. manihoti* was assumed to be 1% from 2007 to year 5 (2011); from year6 up to year 15, it was assumed to be 5% and from year 16 to end of project life it was assumed to be 20%.

(f) It was assumed that farmers did not incur any costs except for extra labour cost to harvest and handle extra output obtained due to reduction in losses occasioned by the project. Information on this extra labour cost was difficult to obtain so it was ignored in the analysis.

(g) Actual costs incurred on releases of *T. manihoti* in project communities from 2008 to 2012 were obtained from RTIMP (Appendix 3). From year 2013 (year 7) to year 10, it was assumed that this cost will increase by 5% per annum. From year 11 to the end of the project, cost of periodic releases and monitoring was assumed to reduce by 20% per annum since *T. manihoti* multiplication rate will be very high and extensive in the later years of the project.



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