AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.

Agricultural Economics Research Review
Vol. 30 (No.2) July-December 2017 pp 223-234
DOI: 10.5958/0974-0279.2017.00044.1

Trait Valuation in Genetically Modified Crops: An *ex-ante* Analysis of GM Cassava against Cassava Mosaic Disease[§]

K.R. Ashok[a]*, Alessandra Giuliani[b], M. Thilagavathi[a], S. Varadha Raj[a], R. Ramamoorthy[a], M. Devi[a] and A. Sanjeevikumar[a]

[a]Department of Agricultural Economics, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India
[b]Bern University of Applied Sciences, School of Agricultural, Forest, and Food Sciences (HAFL), Bern, Germany

Abstract

Cassava is a widely distributed crop known for food security and industrial applications. Nonetheless, it is highly prone to attacks of pests and diseases. Cassava mosaic disease (CMD) is an important cause of loss across the globe. In this context, research is focused on developing cassava mosaic disease resistant varieties through transgenic and conventional approaches. In this paper, the trait of CMD resistance is valued *ex-ante* using partial budget approach and economic surplus model. The trait value of CMD resistance at farm level varies from ₹ 38658 per hectare in drip-irrigated production system to ₹ 15562 per hectare in rainfed production system. At the macro level, the value of the improved trait is worth 1781.70 million rupees. The results clearly indicate attractive rate of returns on investment in research for CMD resistance in cassava.

Key words: GM Crops, Trait Valuation, Cassava, Economic Surplus Model, Partial Budget Analysis

JEL Classification: Q16, O30, O33, O47

Introduction

The tuberous root of cassava (*Manihot esculenta* Crantz) is the fourth most important food source for carbohydrates after rice, maize, and sugarcane and it is staple food for more than 500 million people (Moorthy, 2002; Davis *et al*., 2003; Tonukari, 2004; Blagbrough *et al*., 2010) in tropical and subtropical Africa, Asia and Latin America (FAO, 2008). It is cultivated mostly in tropical countries situated around equator between 30° North and 30° South. Cassava is grown as a subsistence crop by smallholders on marginal and sub-marginal lands with low input use and flexible planting and harvesting seasons. It is a convenient crop for poor farmers as it is a sustainable source of food because of its tolerance to drought and yields good even under poor agronomic and soil management practices. Besides it increases employment opportunities, and enhances rural incomes in the cassava growing regions.

Cassava tuber is also an important raw material for producing starch for industrial applications. Thus, the crop has been transformed from a reserve commodity for support in times of famine into a staple diet, and subsequently to a cash crop (Egesi *et al*., 2006). Though, about 95 percent of the cassava produced in Africa is used for human consumption (Nweke and Haggblade, 2009), in Asia it is used for industrial uses, either for production of animal feed for exports (Thailand and Vietnam) or for industrial starch (India). Nigeria is the largest producer of cassava and accounts for 55 per cent of the global production[1]. India ranks first in productivity with an average of 36.40 tonnes per ha produced on 0.23 million ha

* Author for correspondence
Email: ashok10tnau@yahoo.com
§ This paper is drawn from the socioeconomic component of Indo-Swiss Cassava Network project

(FAOSTAT, 2016). More than 80 per cent of the cassava area in India is concentrated in southern states of Kerala and Tamil Nadu.

Cassava is subjected to many stress factors in its production and post-production stages. Production stress factors are both biotic and abiotic, while post-production stress factors include price instability and uncertain demand. Although socioeconomic factors, market conditions and abiotic constraints negatively affect cassava production, pests and diseases reduce its yield substantially (Anderson and Morales, 2005; Waddington *et al*., 2010; Renkow and Byerlee, 2010). One of the important biotic stresses is the cassava mosaic disease (CMD)[2] which is prevalent in many parts of Africa and South Asia (Calvert and Thresh, 2002; Sseruwagi *et al*., 2004; 2005). The economic loss due to CMD has been estimated to the tune of US$1.9-2.7 (Legg *et al*., 2006). In this background, the Indo-Swiss Cassava Network Project[3] implemented under the aegis of Indo-Swiss Collaboration in Biotechnology (ISCB) aims at developing cassava mosaic disease resistant varieties through transgenic and conventional approaches. Genetic engineering offers various options for introducing transgenic virus resistance into crop plants. RNA mediated silencing technology is the tool of choice for induction of virus resistance in plants. The current research is based on RNAi mediated resistance against CMD (Vanderschuren, 2007; 2009). The study developed transgenic cassava with hairpin RNAi constructs using portion of Sri Lankan cassava mosaic virus genome as source of CMD resistance. As part of the project, the trait of CMD resistance is valued to justify the investment in the project.

Data and Methodology

The study was conducted in Tamil Nadu which accounts for 50 per cent of the area and 64 percent of the cassava production in India (Horticultural Statistics at a Glance, 2015). The cassava yield is higher in the state (31 tonnes per ha) than in any other state. Most of the cassava produced is utilized for industrial production of sago and starch.

Data

A rapid interview with key informants comprising different stakeholders of cassava production shows that cassava is produced in four distinct production systems in Tamil Nadu. Cassava is cultivated in plains and hills. In plains, it is grown as rainfed crop, as drip irrigated and flood irrigated crop. In hills, it is cultivated as rainfed crop. A representative sample of cassava farmers was drawn for data collection in a multistage sampling framework from these four production systems. In the first and second stage respectively districts and blocks were selected based on the highest area under cassava. In the next stage, four villages from each production system were chosen at random from the selected blocks. In the final stage, 15 cassava farmers were selected at random from the 16 selected villages.

Methodology

The need for genetically modified (GM) cassava against CMD is felt at farmer as well as industry level. Different approaches, *ex ante* as well as *ex post,* are used in the literature to measure the economic impact of an improved technology. *Ex-ante* studies are based on perceptions of the researchers, extension workers and social scientists in regard to likely yield, success rate and adoption of technology.

Trait Valuation

The process of identifying and describing the benefits due to a trait of a variety is a complex process. The major diseases in cassava in Tamil Nadu include cassava mosaic disease, cassava bacterial blight, cassava anthracnose and root rot. In this context, an Indo-Swiss Cassava Network Project was implemented under the framework of Indo-Swiss Collaboration in Biotechnology to develop CMD resistant cassava cultivars. This study attempts to investigate whether the prospective GM variety with CMD resistance trait would be economically beneficial to the farmers and industry. The GM cassava is at its product development stage and no field evidence on its performance is available. Hence, an *ex ante* approach is adopted. Researchers have adopted different approaches to assess value of varietal trait. Using a choice experiment approach, one can investigate farmers' crop variety preferences, estimate the willingness to pay for an attribute, and also identify household-specific and institutional factors that govern trait preferences. Often, hedonic price model is used to estimate willingness to pay for a trait. Thus, use of an analytical tool depends on the trait in consideration, purpose for which the valuation is done and availability of data on the parameters required. In this study, we use Partial Budget Analysis (PBA) and Economic surplus model to estimate potential economic benefits from GM Cassava.

Partial Budget Analysis (PBA)

When a farmer contemplates a change in the use of technology PBA can be used to analyse the anticipated costs and benefits of the new technology. Partial budgeting is a statement of anticipated changes in costs, returns and profits. The technique involves only those factors that are changed. It does not consider the farm resources that are left unchanged. The capability of the introduced change in the farm business is evaluated for its incremental effects in a partial budget analysis. In the present study, the cost and benefit of existing cultivated varieties of cassava are compared with GM cassava having the traits of insecticide resistance and herbicide tolerance.

In developing partial budgets, the costs (debit side) and benefits (credit side) due to contemplated changes are estimated. The elements of a partial budget are: added or reduced costs, and added or reduced returns.

Credit = Added returns + Reduced costs

Debit = Reduced returns + Added costs

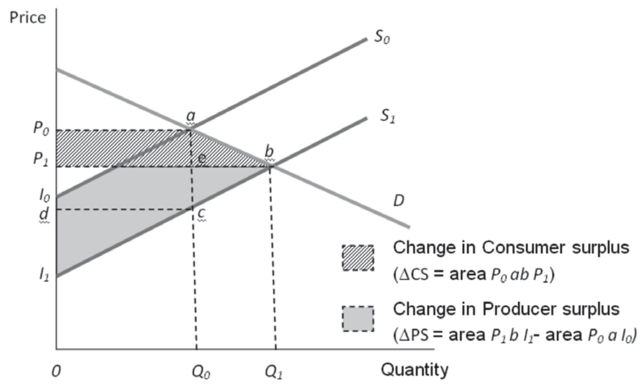
Net Benefit = [Credit – Debit]

A positive change in the net benefit indicates the beneficial technological change.

Economic Surplus Model

Economic surplus modeling has been extensively used to estimate the potential benefits that could result from commercialization of crop improvement process involving new traits. By making appropriate assumptions about the properties of the supply and demand functions and the nature of the technological change (trait), it estimates benefits due to the trait in terms of change in social welfare.

An economic surplus framework considers unit cost reductions and price responses to research-induced quantity shifts and assesses the level and distribution of research benefits. The model shows to what extent to research-induced reductions in unit cost of production and adoption of technology can reduce market prices (Norton and Dey, 1993). Economic surplus analysis considers the nature of the market for the commodity and the fact that prices may fall as production changes and supply increases. Market effects stemming from whether the product is widely traded are considered. In the case of fresh cassava, the closed economy model is used as cassava is not an extensively traded commodity. The economic surplus method measures the change in producer and the consumer surplus (Fig.1).



Source: Alston, Norton and Pardey (1995)

Figure 1. Economic Surplus Model

One of the most important parameters in the economic surplus analysis is the research induced proportionate shift in supply (K factor). For a change in total surplus (TS), which is change in consumer surplus (CS) plus change in producer surplus (PS), in a closed economy with linear demand and supply and a parallel research induced supply shift we assess the impact of introduction of a new technology in the framework developed by Alston *et al.* (1995)[4]:

In Figure 1 S_0 represents supply function before the technical change, and D_0 represents demand function. The initial price and quantity are P_0 and Q_0, respectively. Suppose research generates yield increasing or input saving technologies, these effects can be expressed in terms of reduction in production cost, K, that are modelled as a parallel shift down in the supply function to S_1. This research-induced supply shift leads to an increase in production and consumption to Q_1 ($\Delta Q=Q_1-Q_0$), and the market price falls to P_1 (by $\Delta P=P_0-P_1$). The change in consumer surplus which is the measure of the consumer benefit is equal to area P_0abP_1. The change in producer surplus which is the measure of the producer gain is equal to area P_1bI_1 - area P_0aI_0 in Figure 1. Total benefits or economic surplus is obtained as the sum of producer and consumer benefits. Once changes in economic surplus are projected over time, Internal Rates of Return (IRR), and Benefit-Cost ratios are estimated.

Consumers are better off because the new technology enables them to consume more of the commodity at a lower price (Wood *et al*., 2001). Although they receive a lower price per unit, producers who adopt the new technology are also better off too, because the unit costs have fallen by an amount, K, that is more than the fall in price. Norton *et al*. (2005) state that the distribution of benefits depends on the amount by which the price falls compared to that of costs, as well as the shape the supply shift. If the supply curve shifts in more of a pivotal fashion as opposed to a parallel fashion the benefits to producers would be reduced.

Figure 1 represents the basic static model for research evaluation and it is sensitive to assumptions[5] regarding demand and supply, expected adoption levels, yield increase, change in cost, discount rate, R&D time lag, adoption lag, probability of R&D success and type of adoption. It is also important to account for the timing of streams of benefits and costs and the flow of research benefits. Economic impact of agricultural research and development (R&D) are estimated using 'Dynamic Research Evaluation for Management (DREAM)' software developed by the International Food Policy Research Institute.

Results and Discussion

The summary of costs and returns of cassava cultivation is provided in Table 1 and the detailed information is given in Annexure 2. A one-way analysis of variance (ANOVA) shows statistically significant difference in the yield of cassava across the production systems[6]. It varies from 32 t/ha in drip irrigated system to 21 t/ha in rainfed hill system. The rainfed system is a low input cassava production system. In drip system, fertilizers are applied through drip irrigation directly in the root zone. The cost of cultivation ranges from 1.09 lakh per hectare in drip system to 0.59 lakh per hectare in rainfed hills. The major cost component in the drip system is human labour followed by amortized cost of drip installations. In all production systems, human labour constitutes 50 to 60 per cent of the total cost of cultivation (Annexure 2). Price per tonne of tubers varies from ₹ 7092 to ₹ 5491 depending on the starch content of tubers. The net income is estimated ₹ 1.20 lakh in the drip system, ₹ 1.02 in the flood irrigated system, 0.69 in the rainfed plains and ₹ 0.57 in the rainfed hills.

Trait Value of CMD Resistance at Farm Level: Partial Budget Analysis

The new variety is assumed to have increased yield due to control of CMD and reduction in the use of pesticides for the control of whitefly, which is the vector of CMD. Based on the review of past studies and discussion with farmers and extension personnel, anticipated yield increase is fixed at a conservative estimate of 20 percent and reduced cost due to pesticide is the actual cost of pesticide used. The new technology is embedded in the planting material. Based on the prevailing rates for new varieties the cost of stem is assumed to be ₹ 5. The partial budget estimate of net benefit is the value of new varietal trait. The details are provided in the Table 2.

Table 1. Summary of costs and returns of cassava cultivation

(₹/ha)

Details	Drip irrigation	Flood irrigation	Rainfed plains	Rainfed hills
Total cost (₹)	108744	81840	70650	59214
Average yield (ton/ha)*	32	28	22	21
Price /tonnes of tubers	7092	6676	6257	5491
Gross income	228358	183929	139552	116398
Net income	119614	102088	68902	57183

*F= 688.72, statistically significant difference in yield between four cassava production systems.

Table 2. Partial budget analysis to estimate trait value of CMD resistance

(₹/ha)

	Drip irrigation	Flood irrigation	Rainfed plains	Rainfed hills
Added income *	45389	37386	27531	23062
Reduction in costs of pesticides	769	492	840	0
Subtotal [Credit]	46158	37878	28371	23062
Added costs [sett cost**]	7500	7500	7500	7500
Reduction in return	0	0	0	0
Subtotal [Debit]	7500	7500	7500	7500
Net benefit [Credit-Debit]	38658	30378	20871	15562

*20 per cent increase in yield; **1500 stem per ha @ ₹ 5 /stem

Table 3. Sensitivity of trait value to variability in yield

(₹/ha)

Increase in yield (%)	Drip irrigation	Flood irrigation	Rainfed plains	Rainfed hills
10	15963	11685	7105	4031
20	38658	30378	20871	15562
30	61352	49070	34636	27093
40	84047	67763	48402	38624

The value of the CMD resistance trait is the net benefit obtained. It is estimated ₹ 38658 per hectare in the drip system to ₹ 15562 per hectare in the rainfed system. The *ex ante* trait valuation is highly sensitive to the assumptions made regarding different parameters. The assumption on yield change has considerable influence on the net benefit and hence a sensitivity analysis has been attempted with yield improvements varying from 10 to 40 percent (Table 3). The results indicate that trait value depend on the impact of the trait on yield but also the production system and its associated agro-climatic characteristics.

Trait Value of CMD Resistance at Macro Level: Economic Surplus Model

The economy wide impact of the trait at all India level is analyzed using economic surplus model. The actual project budget is taken as the research cost in the model. Technology life is assumed to be 10 years with a 3 years research lag. The base period in the model is assumed to be 2014. The research investment on the development of CMD resistant varieties yield a B:C ratio ranging from 0.21 to 4.90 depending on the assumptions of yield increase due to new varieties (Table 4). A 10 per cent increase in the yield would generate only 0.21 rupee for every rupee invested in research. Review of past studies and estimates of progressive farmers' and extension personnel put an anticipated yield increase of 20 percent which would give a reasonable B:C ratio of 1.77. Internal Rate of Return (IRR) is the rate at which benefits are realized following an initial investment on research and development of new cassava varieties. The IRR is attractive with an assumed increase of 20 per cent or more in cassava yield. At 20 per cent increase in yield, the IRR for the trait is 14.33, comparable to the rate of interest for long-term investment.

Distributional Impact of the GM technology

The macro level impact of CMD resistance will impact overall production, and hence will have different

Table 4. Economic impact of the GM technology in Cassava

% change in yield	B:C Ratio	IRR
10	0.21	-19.80
20	1.77	14.33
30	3.33	28.50
40	4.90	38.40

Table 5. Distributional impact of technology for the entire technology period

Details*	₹ in Million	Per cent
Producer Surplus	561.35	31.51
Consumer Surplus	1220.34	68.49
Total	1781.70	100.00

*for 20 per cent change in yield

impact on producers and consumers (Table 5). Results indicate a total benefit of ₹ 1781.70 million over the entire span of technology. Of this producers share 31.51 per cent, and the rest is shared by the consumers. In a similar study, Arega *et al*. (2013) estimated benefits from cassava research and extension involving multiplication and distribution of improved and CMD-free planting materials. The results show gross economic benefits of over US$17 million for Malawi and Zambia. The results provide further insights into the distribution of research benefits where 83% of the benefits accrue to consumers, and only 17% of the benefits were captured by the producers. Nderim Rudi (2008) using economic surplus model quantified the additional benefits from marker assisted breeding in cassava as opposed to conventional breeding at US$817 million for Nigeria, US$371 million for Ghana, and US$34 million for Uganda. The additional benefits from research in some of these countries are high compared to India because of higher area under cassava in these countries.

Conclusion

Cassava is an important crop for food security and industrial applications. Cassava mosaic diseases is widespread in India and adversely impacts the yield. Farmers generally do not perceive yield loss due to CMD but accept as an inevitable problem. Among the different control measures suggested for CMD, the most promising one is the use of CMD resistant varieties. Biotechnological research aims at developing cultivars with CMD resistance trait. In this study we have made an *ex ante* assessment of the CMD resistant trait and found its value in the range of ₹ 15562 to ₹ 38658 in different production systems. At the macro level, adoption of CMD resistant variety is expected to generate a surplus worth ₹ 1782 million shared in a ratio of 1:3 between producer and consumers. The IRR on investment in CMD resistance research is quite attractive, suggesting more investment in such a research.

Acknowledgement

The authors express gratitude to Department of Biotechnology, Ministry of Science of technology, Government of India and Swiss Agency for Development and Co-operation, Government of Switzerland for funding the project under the aegis of the Indo-Swiss Collaboration in Biotechnology (ISCB). We thank Dr. M. Prahadeeswaran, Department of Agricultural Economics, Agricultural College and Research Institute (TNAU), Madurai for contributing in analyzing the data. The authors acknowledge with thanks the meticulous comments and suggestions by the anonymous referee.

Notes

1. The largest area under cassava is in Nigeria with 7.10 million hectares accounting 29 per cent of the global area, followed by Congo with 2.06 million hectares (9 per cent), Brazil with 1.57 million hectares (7 per cent), Thailand with 1.35 million hectares (6 per cent) and Indonesia with 1.00 million hectares (4 per cent) in 2014. In terms of production also Nigeria ranks first with 54.83 million tonnes accounting for 20 per cent of the global production followed by Thailand with 30.02 million tonnes (11 per cent), Indonesia with 23.44 million tonnes (9 per cent) and Brazil with 23.24 million tonnes (9 per cent) in 2014. (FAOSTAT, 2016). The above five countries account for more than 50 per cent of the global cassava area and production. In 2014 India produced 8.14 million tonnes of cassava from 0.23 million hectares. India ranked first in terms of productivity with 36.40 tonnes per ha. The productivity was 7.57 tonnes per ha in Nigeria, 8.07 tonnes per ha in Congo, 14.17 tonnes per ha in Brazil, 22.00 tonnes per ha in Thailand and 22.41 tonnes per ha in Indonesia.

2. The earliest report of Cassava Mosaic Disease (CMD) was in 1894 by Walburg and the disease was found to be a viral disease in 1906 by Zimmermann. CMD is caused by Geminiviruses (Geminiviridae: Begomovirus) known as Cassava Mosaic Geminiviruses (CMGs) and transmitted

by *Bemisia tabaci* (Gennadius) (Homoptera: Aleyrodidae) known as white fly which is reported from Africa and the Indian subcontinent (Fauquet *et al*., 2003). The cassava crop in the Americas and South-East Asia are free from disease caused by begomoviruses, but the crop is severely affected by CMD in Africa, Southern India and Sri Lanka, where the disease is caused by the endemic viruses (Varma *et al*., 2011). Nine distinct cassava mosaic viruses have been characterized worldwide from CMD affected plants and seven of them from sub-Saharan Africa. These include: Indian Cassava Mosaic Virus (ICMV), Sri Lankan Cassava Mosaic Virus (SLCMV), African Cassava Mosaic Virus (ACMV), East African Cassava Mosaic Virus (EACMV), East African Cassava Mosaic Cameroon Virus (EACMCV), East African Cassava Mosaic Kenya Virus (EACMKV), East African Cassava Mosaic Malawi Virus (EACMMV), East African Cassava Mosaic Zanzibar Virus (EACMZV) and South African Cassava Mosaic Virus (SACMV) (Alabi *et al*., 2011). White fly, a serious agricultural pest reported on more than 600 crops and weed hosts and act as vector of 111 recognized economically devastating plant viruses. In India, *B. tabaci* is reported to be the vector of ICMV. According to Hillocks and Thresh (2000) variability in the pathological variables of CMD is often attributed to several factors such as different strains of virus, susceptibility and age of the host plant, and environmental factors such as soil fertility, soil moisture, solar radiation and temperature. The number of *B. tabaci* per plant varied also from site to site. This variability appears to be related to varietal preference by *B. tabaci* (Sserubombwe *et al*., 2001). CMD is transmitted through planting of CMD infected cuttings or through transmission by the vector whitefly. Kumar *et al*. (2014) reported that high infection rate was (89.09%) due to use of infected planting material (stem cuttings), while the whitefly borne infection was found to be very low (10.01%).

3. Indo-Swiss Cassava Network Project is implemented by Indo-Swiss Collaboration in Biotechnology (ISCB), a bilateral research and product development programme jointly funded and steered by the Swiss Agency for Development and Co-operation, Government of Switzerland and Department of Biotechnology, Ministry of Science of technology, Government of India in partnership with Central Tuber Crops Research Institute (CTCRI) Thiruvananthapuram, Tamil Nadu Agricultural University, Coimbatore ETH Zurich and HAFL Bern.

4. $\Delta TS = P_0Q_0\, K\, (1+ 0.5Z\eta)$

   $\Delta CS = P_0Q_0\, Z\, (1+ 0.5Z\eta)$

   $\Delta PS = P_0Q_0\, (K\text{-}Z)\, (1+ 0.5Z\eta)$

   where,

   P_0 and Q_0 are initial equilibrium price and quantity, respectively

   $Z = K\varepsilon/(\varepsilon+ \eta)$ relative reduction in price due to supply shift

   ε = supply elasticity

   η = demand elasticity (absolute value)

   K = shift of the supply curve as a proportion of the initial price: The proportionate shift of the supply curve K can be calculated as:

   $K = (E(Y)/ \varepsilon – E(C)/1+E(Y))\, p\, A_t\, (1\text{-dt})$

   where,

   E(Y) = expected proportionate yield Δ (per Ha) from adoption of new technology

   E(C) = expected proportionate Δ in variable input costs (per Ha) from adoption

   p = probability of success of achieving the expected yield Δ from adoption

   A_t = adoption rate of technology in time t

   d_t = rate of depreciation of the new technology

5. Demand and Supply Elasticities: Since there are no reliable estimates of price elasticity of demand for Tamil Nadu; estimating own-price elasticity of cassava requires extensive data and a new study by itself. Estimates of the elasticity of demand in other countries available in the literature are used in the study. Tsegai and Kormawa (2002) used the AIDS model to estimate the cassava demand elasticity in Nigeria and found that the price elasticity of demand to be - 0.46. Nderim Rudi

(2008) used - 0.46 as the elasticity of demand in estimating the economic surplus model.

Alston *et al.* (1995) recommend the use of supply elasticity equal to 1 when not available. They state that in the long run all supply elasticity can be high because in the long-run most fixed factors become variable. Long run elasticity for most agricultural commodities is greater than one, while short run and intermediate elasticity is usually close to one. Since there is no exact supply elasticity for cassava available for Tamil Nadu, the supply elasticity for cassava is set at 1.0.

6. Expected adoption levels: Expected adoption levels for a new variety represent one of the key variables in measuring the economic surplus generated by the new technology. The level of adoption is expected to depend on the success of the new technology in providing resistance to the target stresses and providing higher yields. Scientists interviewed by Nderim Rudi (2008) suggested that the maximum base adoption rate for new cassava varieties will be 40 per cent for CMD and whiteflies resistance. In India if the CMD resistance is transferred to popular varieties adoption level is assumed to be 60 per cent based on the opinion of extension experts.

7. Yield increase: Different estimates of the economic losses due to CMD have been reported depending on the location or year. Estimated tuber yield reduction due to CMD ranged from 20 to 90 per cent [Annexure 1]. When there is GM cassava with CMD resistant trait is available the yield loss due to CMD is avoided. Yield loss avoided is the yield increase realized by the farmers. Most of the studies put it around 40 per cent.

8. Change in cost: Change in cost was worked out to be an increase of 9.36 per cent. There is no cost for setts at present as the farmers reuse or exchange the setts free of cost. In the past farmers paid for new varieties. Hence ₹ 5 per stem was assumed for the improved variety with CMD resistance. Farmers can reuse the stems of cassava without losing the improved trait as it is vegetatively propagated. But the sale of stems of new varieties will continue till such time the variety spreads the entire region. It will take few years because of the low stem multiplication rate. The change in cost was arrived by assuming purchase of 1500 stem@ ₹ 5 per stem and 8 cutting per stem totalling 12000 setts per hectare.

Discount Rate: Discount rate is assumed to be 3 per cent considering the prevailing interest rate net of inflation.

Other Assumptions: Other assumptions include base period is 2014, R&D time lag of 6 years, an adoption lag of 3 years, probability of R&D success at 80 per cent and sigmoid type of adoption.

9. Equality of means of yield: one-way ANOVA: An one-way analysis of variance (ANOVA) was used to understand whether there is a difference in yield of the four production systems. An one-way analysis of variance (ANOVA) showed statistically significant (P=0.000) difference in yield between the four cassava production systems. To know which of the production system pairs were differed in yield pairwise comparison of means were done with post hoc tests. The results were given below.

Source	SS	df	MS	F	Prob>F
Between groups	777784820.00	3	259261607.00	688.72	0.000
Within groups	88839864.60	239	376440.10		
Total	866624684.60	239	3626044.71		

Comparison of pair-wise yield by production system

Row mean / Col mean	1	2	3
2	-1871.25 (0.000)		
3	-4105.00 (0.000)	-2233.75 (0.000)	
4	-4445.83 (0.000)	-2574.58 (0.000)	-340.833 (0.016)

References

Alabi, O.J, Kumar, P.L. and Naidu, R.A. (2011) Cassava Mosaic Disease: A curse to food security in Sub-Saharan Africa. *APSnet Features*.doi:10.1094/APSnetFeature-2011-0701.

Alston, J.M., Norton, G.W. and Pardey, P.G. (1995) *Science under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting.* Cornell University Press, Ithaca, New York.

Anderson, P.K. and Morales, F.J. (2005) Whitefly and whitefly-borne viruses in the tropics: building a knowledge base for global action. In: CIAT Publication. Cali, Colombia: International Center for Tropical Agriculture.

Arega D. Alene, R. Khataza, C. Chibwana, P. Ntawuruhunga and C. Moyo (2013) Economic impacts of cassava research and extension in Malawi and Zambia, *Journal of Development and Agricultural Economics*, 5(11), 457-469.

Blagbrough, I.S., Bayoumi, S.A.L., Rowan, M.G. and Beeching, J.R. (2010) Cassava: An appraisal of its phytochemistry and its biotechnological prospects. *Phytochemistry*.**71**(17-18) :1940-1951.

Bouwmeester, H., Heuvelink, G.B.M., Legg, J.P. and Stoorvogel, J.J. (2012) Comparison of disease patterns assessed by three independent surveys of cassava mosaic virus disease in Rwanda and Burundi. *Plant Pathology*. **61**(2): 399-412.

Calvert, L.A. and Thresh, J.M. (2002) The viruses and virus diseases of cassava. In: *Cassava: Biology, Production and Utilization*, Eds: R.J. Hillocks, J.M. Thresh, A.C. Bellotti, U.K. Wallingford. CAB International, pp 237-60.

Cudjoe, A., James, B. and Gyamenah, J. (2005) Whiteflies as vectors of plant viruses in cassava and sweet potato in Africa-Ghana. In: *whitefly and whitefly-borne viruses in the tropics*: Building a knowledge base on Global action. CIAT, Colombia. pp. 24-29.

Davis, J.P., Supatcharee, N., Khandelwal, R.L., Chibbar, R.N. (2003) Synthesis of novel starches in planta: opportunities and challenges. *Starch-Stärke*, **55**(3-4): 107-120.

EARRNET (2015) Ecologically sustainable plant protection.Retrieved February 1, 2015 from http://www.asareca.org/earrnet/plant_health.html.

Edison, S., Anantharaman, M. and Srinivas, T. (2006). Status of cassava in India an overall view. CTCRI, *Technical Bulletin Series*: 46, p. 11-157.

Egeisi.C., Mbanaso, E., Ogbe, F., Okogbenin, E. and Fregene, M. (2006) Development of cassava varieties with high value root quality through induced mutations and marker-aided breeding. NRCRI, Umudike Annual Report 2006.

FAO (Food and Agricultural Organization of United Nations) (2010) *Cassava diseases in Central, Eastern and Southern Africa (CaCESA)*: Strategic programme framework, 2010-2015. p 1-58.

FAO (Food and Agricultural Organization of United Nations) (2008) www.faostat.org Rome, Italy: Food and Agriculture Organization of the United Nations.

FAOSTAT (2016) FAO database. Rome, Italy: Food and Agriculture Organization of the United Nations.

Fargette, D. and Fauquet, C. (1998) A preliminary study of intercropping maize and cassava on the spread of African cassava mosaic virus by whiteflies. *Aspects of Applied Biology* **17**: 195-202.

Fauque, C. and Fargette, D. (1990) African cassava mosaic virus: etiology, epidemiology and control. *Plant Disease*74(6): 404-411.

Fauquet, C. M. and Stanley, J. (2003) Geminivirus classification and nomenclature: progress and problems. *Annals of Applied Biology* **142**: 165-189.

Hillocks, R. J., Thresh. J.M. (2000) Cassava Mosaic and Cassava Brown Streak Virus Diseases in Africa: A Comparative Guide to Symptoms and Etiologies. *Roots*, **7**(1): 1-8.

Horna, D., Smale, M. and Zepeda, J. F. (2006) *Assessing the Potential Economic Impact of Genetically Modified Crops in Ghana*: Tomato, Garden Egg, Cabbage and Cassava. PBS report, October, IFPRI.

Horticultural Statistics at a Glance (2015) Ministry of Agriculture & Farmers Welfare, Government of India

Kumar, J., Rabindran, R., Singh, H. and Kumar, P. (2014) Molecular studies on the transmission of Sri Lankan cassava mosaic virus (SLCMV) in cassava by Bemisia tabaci collected from cassava and cassava based crops. *J Cell Tissue Res.* 14(3):4556-4564.

Legg, J.P., Owor, B., Sseruwagi, P. and Ndunguru, J. (2006). Cassava mosaic virus disease in East and Central Africa: Epidemiology and Management of a Regional Pandemic. *Advances in Virus Research.* **67**: 355-418.

Legg, J.P. and Thresh, J.M. (2003) Cassava virus diseases in Africa. In: *Proceedings of the First International Workshop on Plant Virology in Sub-Saharan Africa*. IITA, Ibadan, pp. 517-552.

Moorthy, S.N. (2002) Physicochemical and functional properties of tropical tuber starches: a review. *Starch-Stärke*, **54**(12): 559-592.

Nderim Rudi (2008) *An ex ante economic impact analysis of developing low cost technologies for pyramiding* *useful genes from wild relatives into elite progenitors of cassava*, Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University

Norton, G. W. and Dey, M. (1993) Analysis of Agricultural Research Priorities in Bangladesh. ISNAR Discussion Paper: 1-75.

Norton, G.W., Moore, K., Quishpe, D., Barrera, V., Debass, T., Moyo, S. and Taylor, D.B. (2005) Evaluating Socio-Economic Impacts of IPM, In: *Globalizing Integrated Pest Management*: A Participatory Research Process, Eds G. W. Norton, E. A. Heinrichs, G. C. Luther and M. E. Irwin, Blackwell Publishing, Ames, Iowa, USA.

Nweke, F., and Haggblade, S. (2009) Africa's cassava surge. In: *Successes in African agriculture: Lessons for the future*, Eds. S. Haggblade and P. Hazell. Baltimore, Md., U.S.A.: Johns Hopkins University Press.

Otim-Nape, G.W., Thresh, J.M. and Fargette, D. (1996) *Bemisia tabaci* and cassava mosaic virus disease in Africa. In: *Taxonomy, biology, damage, control and management*, Eds: D. Gerling and R.T. Meyer. *Bemisia* 1995: Andover, pp. 319-350.

Owor, B. (2002) *Effect of cassava mosaic geminiviruses (CMGs) on growth and yield of a cassava mosaic disease (CMD) susceptible cultivar in Uganda and cross protection studies*.M.Sc.Thesis, Makerere University, Kampala, Uganda.

Renkow, M. and Byerlee, D. (2010) The impacts of CGIAR research: A review of recent evidence. *Food Policy*. **35**(5): 391-402.

Sserubombwe, W.S., Thresh, J.M., Otim-Nape, G.W., Osiru, D.O.S. (2001) Progress of cassava mosaic virus disease and whitefly vector populations in single and mixed stands of four cassava varieties grown under epidemic conditions in Uganda. *Annals of Applied Biology* **138**: 161-170.

Sseruwagi, P., Okao-Okuja, G., Kalyebi, A., Muyango, S., Aggarwal, S. and Legg, J.P. (2005) Cassava mosaic geminiviruses associated with cassava mosaic disease in Rwanda. *International Journal of pest Management*. **51**: 17-23.

Sseruwagi, P., Sserubombwe. W.S., Legg, J.P., Ndunguru, J. and Thresh, J.M. (2004) Methods of surveying the incidence and severity of cassava mosaic disease and whitefly vector populations on cassava in Africa: a review. *Virus Research*. **100**: 129-142.

Thresh, J.M. and Otim-Nape, G.W. (1994) Strategies for controlling African cassava mosaic geminivirus. *Advances in Disease Vector Research*. **10**: 215-236.

Thresh, J.M., Ottim-Nape, G.W., Thankappan, M. and Muniyappa, V. (1998) The mosaic diseases of cassava in Africa and India caused by whiteûy-borne geminivirus. *Annual Review of Plant Pathology* **477**: 935-945.

Tonukari, N.J. (2004) Cassava and the future of starch. *Electronic Journal of Biotechnology* **7**(1): 5-8.

Tsegai, D. and Kormawa, P. (2002) "Determinants of urban households demand for cassava and cassava products in Kaduna, northern Nigeria: The application of AIDS model" Kassel-Witzenhausen.

Vanderschuren, H., Akbergenov R., Pooggin M.M., Hohn T., Gruissem, W. and Zhang, P. (2007) Transgenic cassava resistance to Africa cassava mosaic virus is enhanced by the virus promoter derived siRNAs. *Plant Molecular Biology*, **64** (5), 549-557.

Vanderschuren, H., Alder, A., Zhang, P., Gruissem, W. (2009) Dose-dependent RNAi-mediated geminivirus resistance in the tropical root crop cassava. *Plant Molecular Biology*, **70**(3), 265-72.

Varma, A., Mandal, B. and Singh, M.K. (2011) Global emergence and spread of whitefly (*Bemisiatabaci*) transmitted geminiviruses. **In:** Thompson WMO, editor. The whitefly, *Bemisiatabaci* (Homoptera: Aleyrodidae) interaction with geminivirus-infected host plants. Netherlands: *Springer*. p. 205-292.

Waddington, S.R., Li, X., Dixon, J., Hyman, G., Vicente, M.C. (2010) Getting the focus right: Production constraints for six major food crops in Asian and African farming systems. *Food Securiety* **2**(1): 27-48.

Wood, S., Liangzhi, Y. and Wilfred, B. (2001) DREAM Version 3, User Manual, International Food Policy Research Institute, Washington, D.C., U.S.A.

Zhang, P., Vanderschuren, H., Futterer, J. and Gruissem, W. (2005) Resistance to cassava mosaic disease in transgenic cassava expressing antisense RNAs targeting virus replication genes. *Plant Biotechnology Journal.* **3**: 385-397.

Zinga, I., Nguimalet, C., Lakouetene, D.P., Konate, G., KoshKomba, E. and Semballa, S. (2008) The impacts of African cassava mosaic disease in Central African Republic. Geol. *Ecol. Trop*. **32**: 47-60 (in French).

Received: February, 2017; Accepted: August, 2017

Annexure 1. Estimated tuber losses due to CMD

Sl No	References	Tuber loss %
1	EARRNET (2015)	20-90
2	Bouwmeester *et al*. (2012)	Up to 47
3	FAO (2010)	80
4	Fauquet and Fargette (1990)	50
5	Zinga *et al*. (2008)	67-97
6	Horna *et al*. (2006)	60
7	Edison *et al*. (2006)	25-80
8	Legg *et al*. (2006)	12-82
9	Zhang *et al*. (2005)	20-28
10	Cudjoe *et al*. (2005)	27-30
11	Legg and Thresh (2003)	30-40
12	Owor (2002)	12-82
13	Calvert and Thresh (2002)	30-40
14	Fargette *et al*. (1998)	37
15	Thresh *et al*.(1998);	20-90
16	Otim-Nape *et al*. (1996)	40-50
17	Thresh *et al*. (1994)	30-40

Annexure 2. Costs and returns of cassava in the four production systems

Sl No	Costs/Returns	Drip irrigation			Flood irrigation			Rainfed plains			Rainfed hills		
		Qty	Value	%	Qty	Value	%	Qty	Value	%	Qty	Value	%
1	Human labour (Man days)	148.23	56945.11	52.36	166.60	49877.64	60.94	147.22	44175.00	62.52	127.53	38241.77	64.58
2	Machine labour (Hrs)	17.38	12313.97	11.32	10.92	7521.15	9.19	09.21	6219.79	08.80	07.51	4507.75	07.61
3	Stem cuttings (Nos)	12500.00	00.00	00.00	13750	00.00	00.00	15000	00.00	00.00	15000	00.00	00.00
4	Fertilizer and manures												
4.1	Organic manure (tonnes)	03.04	3807.92	03.50	08.76	10522.20	12.85	06.37	7968.75	11.27	03.58	4297.80	07.25
4.2	Inorganic fertilizers (kgs)	600.20	8753.64	08.04	1013.71	12958.13	15.83	722.06	11446.86	16.20	600.61	12166.80	20.54
5	Plant protection chemicals												
5.1	Herbicide (li/ha)	01.90	634.99	0.58	01.09	469.09	0.57	00.00	00.00	00.00	00.00	00.00	00.00
5.2	Insecticide (li/ha)	01.70	768.78	0.70	01.51	492.14	0.60	01.04	839.58	01.18	00.00	00.00	00.00
6	Drip cost* (₹)		25520.00	23.46		00.00	0.00	00.00	00.00	00.00	00.00	00.00	00.00
7	Total cost (₹)		108744.41			81840.35			70649.98			59214.12	
8	Average yield (ton/ha)	32.19			27.54			22.30			21.19		
9	Price of tubers/tonnes #		7092.20			6676.28			6257.24			5491.30	
10	Gross income (₹)		228358.00			183928.60			139552.30			116397.60	
11	Net income (₹)		119613.59			102088.25			68902.32			57183.48	

Note: *Amortized drip cost of ₹ 1 lakh for 6 years @10%. # Cassava price varied according to starch content and depends upon the variety and production system

Amortized cost $A = P.\frac{r(1+r)^n}{(1+r)^{n-1}}$