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Full Length Research Paper

Profitability and sustainability of modern fish farming in Benin: An on-farm experimental appraisal of two production systems of *Clarias gariepinus*

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An on-farm experimental appraisal was done to compare the profitability of two production systems of *Clarias gariepinus* in Benin, and to assess the challenges of modern fish farming in West Africa. The results showed that fish farming using above ground tanks (AGT) was not profitable enough to reward production and recover capital costs, should the investments be fully bank loan-funded. At present feed prices, it cannot cost-effectively meet the market demand, and can only provide proteins to producers' households for their own consumption. On the contrary, Lake Water-fed Pond (LWP) fish farming of *Clarias gariepinus* was ten-fold more profitable (profit rate of 57.7%) than AGTs. Although, its profit rate is still far below the potential performance level in the sub-region, it should be promoted among Lake Village cooperatives or young rural entrepreneurs to meet the growing fish demand, especially from Nigeria. Therefore, financial support should be made available to face the high costs of initial investments. Likewise, considering their lower investment costs, AGTs can also be promoted among urban farmers, only if cost-effective local substitutes to imported feeds become available. There is a need to install quality feed production enterprises to promote both fish production systems towards sustainability, food security and economic development.

Key words: Modern fish farming, lake water-fed ponds, above-ground tanks, *Clarias gariepinus*, profitability, sustainability.

INTRODUCTION

Aquaculture plays a key role in fighting hunger and poverty and promoting rural development. Fresh water and coastal fisheries traditionally provide an important source of food and livelihood for millions of people. However, West Africa is facing the exhaustion of aquatic resources, especially through unsustainable fishing practices. Too much fishing pressure is causing over-exploitation of fish stocks and threatening the contributions they can make to food security and poverty reduction. One quarter of all fish stocks are exploited

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Table 1. Low productivity of fish farming in traditional extensive systems in Southern Benin.

Water surfaces	Annual total production (tons)	Number of fishermen	Annual productivity (ton/fishermen)
Nokoue Lake	19060.43	10452	1.82
Porto-Novo Lagoon	2421.81	5537	0.44
Oueme Delta	2461.82	10284	0.24
Toho Lagoon	90.03	219	0.41
West Coast Lagoon	784.44	2658	0.30
Sazoué River	136.38	307	0.44
Ahémé Lakes Complex*	858.08	9786	0.09
Southern Benin	*25812.99*	*39243*	*0.66*

* Ahémé, Toho, Togbadji and Doukon. Source: Adapted from Sohou et al. (2009).

beyond sustainable levels, and half are fully exploited, with no potential increases in production (African Union, 2003; Sohou et al., 2009).

In Benin, fish farming contributes 11.3% to agricultural GDP (FAO, 1991) but most of this comes from traditional fish harvesting, which is not sustainable due to resource exhaustion practices and biologic water pollution. Indigenous aquaculture is practiced in the departments of Ouémé, Plateau, Mono, Couffo, and Atlantique which represent 43.4% of total population, that is, 4343797 people (INSAE, 2013). Among these, fisheries communities represent about 20%, with average productivity in 1997 of only 0.66 ton of fish per fisherman (Table 1).

Considering the ongoing aquatic resource exhaustion so far, the yield of traditional fisheries today (that is, 20 years later) would be quite ridiculous and explains the growing poverty among these communities. Per capita fish consumption in Benin is now only 12 kg/year (MAEP, 2009), against more than 20 kg/year worldwide (FAO, 2014)[1]. Most of that consumption is fulfilled with importation. Indeed, fish is among the top four imported foods (rice, chicken, fish and milk products), representing altogether 60-100 billion CFA annually (MAEP and MEF, 2010). About 54 000 tons of live or frozen fish worth 22 billion CFA were imported in 2016 (INSAE, 2016)[2], which represents a heavy burden for the country's trade balance.

Hence, there is a need to develop modern fish farming in Benin to meet the country's needs in animal proteins and accelerate poverty reduction through fish exportation to rewarding markets. In that perspective, modern fish farming was among the top priorities in Benin's Strategic Plans for developing the agricultural sector (PSRSA 2010-2015 and PDSA 2016-2021). Various sorts of infrastructure are being promoted, with the aim to develop appropriate fish production systems that would help meet domestic demand more cost-effectively but also supply other West African countries. Fish production raised include African catfish, Tilapia, Captains, etc. The African catfish (*Clarias gariepinus*) is particularly demanded in Nigeria, which is the largest fish consumers in West Africa. The current demand for fish in Nigeria is about four times the level of local production (Ozigbo et al., 2014), and that demand is expected to increase. Hence, Nigeria represents a big market opportunity for modern fish farming in Benin.

Modern fish farming is quite recent in Benin and is practiced by a few retired civil servants. It concerns mostly Catfish (*Clarias gariepinus*), Tilapia (*Oreochromis niloticus*) and Common carp (*Cyprinus carpio*). However, fish importation in Benin represents a huge constraint to competitive domestic modern fish production. The latter can be promoted to meet domestic needs only if it is substantially profitable, considering the relatively high investment costs required. Competition from imported fish can be also faced more efficiently if quality of marketed fish is improved. Upfront of the value chain, there is need to develop adequate production systems and management practices that can be widely adopted by farmers.

This paper compares the financial profitability of two fish production systems - Lake Water-fed Fish Ponds (LWP) and Above Ground Fish Tanks (AGT) - and discusses the conditions of their sustainability for the production of *Clarias gariepinus* in Benin. The development issue at stake is about appropriately directing investment support to fish farmers to develop production systems that are suitable for their investment capacity and locations (peri-urban farms, rural valleys and lakes, rural uplands). Should the government support investments in modern high-productivity infrastructure among rich farmers, or rather promote high-yielding fish production systems among low-to-middle income farmers, or both? In Asia, the implementation of policies to promote aquaculture development, improve governance and capacity factors, as well as institutional arrangements, public-private partnerships and pioneering companies and individuals, were found to create enabling conditions for thriving aquaculture sectors (Williams, 1999).

[1]FAO (2014). http://www.fao.org/news/story/en/item/421871/icode/
[2]INSAE (2016). www.insae-bj.org/?file=files/publications/commerce-ext/...pdf

Whether focus is on export earnings or national food security, any investment decision should be based on the profitability and sustainability of the proposed production systems. Indeed, there is need in Benin to distinguish between rich urban fish farmers, most of which are retired civil servants, and resource poor fishermen that derive most of their livelihoods from lakes and cannot individually afford expensive infrastructure. Yet, the abundant water resources available to the latter require optimal use to enable these communities get out of poverty and improve their livelihoods. Therefore, profitable (productivity-enhancing), environmentally sound and economically affordable production systems should be promoted among them. That's the development perspective of this paper.

LITERATURE REVIEW

Fish farming practice in West Africa

FAO (2003) identified three methods of fish farming: extensive system, semi-intensive system and intensive system according to increasing intensity of capital use and decreasing labor use. In West Africa, fish farming is being practiced under traditional/extensive systems since many centuries and is slowly evolving towards semi-intensive systems. In Nigeria, aquaculture dates back to the 1940s at Onikan Experimental farm, South West Lagos and the 160 ha industrial scale fish farm, Middle Belt, Panyam, Jos in 1951. Since then, great expansion has been witnessed in Nigeria's aquaculture industry, graduating from extensive practice to super-intensive systems (Akegbejo-Samsons and Adeoye, 2012). In Uganda, aquaculture was introduced as a non-traditional farm technology in the late 1950's, catfish and Nile tilapia representing today about 95% of total production (Kasozi et al., 2014).

In Benin, traditional fish farming systems are made of in-lake wooden enclosures charged with tree leaves, known as "*Acadja"*, for natural reproduction and growth of various fish species that are harvested after a while. Practiced by poor fishing communities since more than a century, they are extensive systems that cannot meet today's growing demand in fish. Capture of immature fishes, river pollution and overall exhaustion of natural resources are also other problems accruing from these systems (Sohou et al., 2009). Alternatively, artisanal, small-scale semi-intensive fish farming with fish ponds are used. Such ponds are made of durable materials and are installed next to the lake, with a moto-pump to ensure water rotation. Fish farming families are also using in-door AGT. AGT can be easily moved from one place to another. In particular, raising *Clarias gariepinus* in AGT requires enough and quality water, and other basic technical conditions. In the practice, only a few among modern fish farmers in West Africa follow these recommendations. As a result, average yields are still far below potential yields.

Profitability of existing fish farming systems in Africa

Experimental artisanal farming of *Clarias* has been conducted on small plots of 4 – 20 ares[3] near Bangui (Central Africa). Average yields were 180 kg/are in monoculture and 90 kg/are in polyculture with tilapia. Profit rate were about 137 to 164% in monoculture, 88 to 139% in polyculture, and 113% in mixed farms. Basic price and yield assumptions for small 4 are-plots referred to artisanal farming in quasi autonomous situation. Such profitability levels indicate that artisanal fish farming in Bangui neighborhoods could be very profitable if practiced under such conditions. The observed performance levels could be improved with complete mastering of feed procurement (fingerling) and farming method (PROVAC, 2013).

Apparently, there is hope for profitable fish farming business in Bangui surroundings, but practice may see dreams vanish. For example, despite the advancement of aquaculture industry in Nigeria, especially modern fish farming, the industry contributes only 20% to the country's local fish production. Only 25% of aquaculture enterprises in South West Nigeria were profitably operated, while 75% were not (Akegbejo-Samsons and Adeoye, 2012). Fish species raised and the nature of feeds used are critical determinants of fish farming profitability. The results of an experiment on Nile Tilapia (*Oreochromis niloticus* Linnaeus 1757) in Semi Flow through culture system suggested that fish fed with multi-feed were more profitable than those fed with NIOMR feed (Yakubu et al., 2014). Ike and Chuks-Okonta (2014) found that cost of feeds was the most sensitive cost item in aquaculture fish production in Delta State areas of Nigeria. Maximum variable profit would be increased by the adoption of measures that would reduce the price of feeds.

Modernizing fish farming and prospects for urban fish farming development

The recovery of investment and operational costs and substantial profits to ensure business viability and expansion are critical in a business-oriented choice of fish farming systems. Sautier et al. (2006) reported that fish production increased in many Asian countries during the last decade. However, aquaculture's contribution to food security, nutrition and economic development varies because of unequal capacity and opportunity for modernizing fish farming. The analysis of trade patterns suggests several reasons why this might be the case, including end markets, government support and assistance, ability to react to changing market demands,

[3] 1 are = 100 m^2

ability to adopt regulations required for market access (both domestic and international), production scale and investment in infrastructure. Among these reasons, access to inputs, technical know-how and education are the main shortcomings to increasing aquaculture's outputs.

The same reasons hold in West Africa where modern fish farming has remained quite an orphan sub-sector in agricultural development programs, with quite sporadic projects in the framework of hesitant policies. Indeed, depending on the country and donor funds availability, the fisheries sector belongs either to the ministry of agriculture or to the ministry of environment and water, with therefore unstable, unfocused and sometimes contradictory programs. Actually, strong policies to develop private fish farms and facilitate producers' access to reliable markets have not been implemented. Today, massive importation of frozen or canned fish and meat is discouraging domestic production, while there is growing concern about quality and safety of such imported foods (Sautier et al., 2006).

In order to address the above constraints in the framework of NEPAD's Comprehensive African Agricultural Development Program (CAADP), FAO implemented recently in many West African countries, a few big regional fisheries projects (FAO/SFW, 2012)[4]. It is expected that National Agricultural Investment Plans (NAIPs), backed by UEMOA's Regional Agricultural Investment Plan (RAIP) will build on FAO's and other regional projects' experience and support to promote profitable and sustainable modern fish farming in relevant countries. Actually, one should be cautious in choosing a development path. It is likely that combining many types of profitable production systems will be required. Indeed, small and medium-sized farms are typically more efficient producers than large farms in low-income countries and have better consumption and investment patterns for stimulating growth in the non-farm economy. Broad-based agricultural development in turn requires equitable access to land, modern farm inputs, credit and market (IFPRI/ODI, 2005; Heltberg, 1998; Hazell and Roell, 1983; Mellor, 1976). It is also critical to consider the role of women in such a sector like fisheries. In this regard, the lack of market access and inability to secure fair and consistent prices can perpetuate the ongoing cycle of poverty and high risk for the marginalized (especially women), who are unable to plan and save because of highly volatile market. Innovation is therefore key to ensuring agro-enterprises can adapt to changing market conditions and remain competitive (Collett and Gale, 2009).

In Benin, while reflections are underway about a potential support to fishermen cooperatives to install modern fish ponds or basins for fish farming in many rural fisheries communities, the use of AGT by urban families to produce fish either for their own consumption or for sale is also being explored. Several types of AGT made of various sorts of materials (wood, zing, glass, Plexiglas, plastic, etc.) are available today in the market. However, the conditions of their profitability and sustainability are not yet sufficiently documented. PROVAC (2014) reported that the choice of a type of AGT infrastructure is determined by farmers' financial capacity, kind of fish enterprise envisaged (fingerling production and table food market production), and technical knowledge. In fingerling production, operators raise fingerling for sale to commercial fish farmers and wholesalers. While in table food market production, operators grow fingerlings to table market size for restaurants, food stores, farmers and markets, etc.

MATERIALS AND METHODS

Data were obtained from field practice, an on-farm case study in 2012 in the framework of a technical partnership between the Faculty of Agronomic Sciences/University of Abomey-Calavi and private farms in Benin.

Overview of the case study

Clarias gariepinus husbandry was conducted in 2010 on a 5 ha private fish farm which was created in 1984. The farm is located in the village of Djèrègbé, Sèmè-Kpodji District, near Nigeria border. That district lies mostly on hydromorphic soils resulting from leaching and sedimentation, and therefore suitable for fisheries. The two types of infrastructures –LWP and AGT – form the basis for yields, returns and costs comparison in the present case study. They were supplied with fish seeds (fingerlings) the same day, so that feed quantities and other production costs could be estimated according to the farm's practices[5]. The technical itinerary of Clarias raising included: preparation of breeding infrastructures (cleaning/dirty water removal from enclosure or getting AGT ready), fingerlings input to infrastructure, and control fishing every 17 days after fingerlings supply. Ration was provided as specified in fish feeding calendar, in relation with growth indicators.

Fishes were nourished with imported feed (COPPENS) in relation with weights recorded at control fishing (Table 2). Feeding frequency was twice per day (morning and afternoon). Ration was calculated according to the formula below:

Biomass (Kg) = Number of fishes × average weight
Quantity of feed = Biomass (kg) × Nourishing rate (% weight/day)

[4] In the broad perspective of preserving and adding value to water resources in West Africa, FAO Sub-regional Office for West Africa (SFW) supported the implementation of sub-regional aquaculture projects to develop sustainable fisheries through Regional cooperation. The lack of improved fish seed infrastructure to increase fishing productivity constitutes a major constraint to sustainable fisheries' development. SFW supported the installation of Fish Aggregating Devices (FADs) in 5 Islands of Cape Verde, the implementation in Ghana of the Tilapia breeding program with the 7th Generation of 'Akossombo strain' to benefit hatcheries and farmers shortly, and Trainings in Nigeria on best business practices from pond construction to marketing (FAO/SFW 2012).

[5] The farm is a reference farm, as it is a pilot site for Ministry of Agriculture's PROVAC training program for fish producers. The promotor got the appropriate training in fish farming techniques in 2010 from the PROVAC project of Ministry of Agriculture, and a financial support in 2011.

Table 2. Feeding ration of *Clarias gariepinus* according to fish weight.

Weight (g)	Nourishing rate (% weight/day)	Weight (g)	Nourishing rate (% weight/day)
10	5.9	300	2.5
30	4.8	400	2.2
50	4.3	500	1.9
100	3.6	600	1.6
200	2.9		

Source: The on-farm case study.

Method of assessing profitability and sustainability

Partial production budget and complete operating farm account were used on data from a modern private fish farm. Partial budget of each system was prepared using variable costs (inputs; specific materials that depreciate and exhaust completely in less than one year; and wage of occasional labor) and specific fixed costs (depreciation of infrastructure–machinery and heavy equipment; salaries of permanent labor; and overheads–taxes, rents, electricity, etc.). Complete farm budget or operating account considers the addition of general costs including depreciation of infrastructure and production costs that are common to both systems.

In that farm account, the budget lines include: Gross return which is quantity produced times selling price. Production costs include variable and fixed costs as explained above. The gross margin is gross return minus variable costs. Unit or per kg gross margin is gross margin divided by quantity of fish produced. It allows the comparison of production systems rearing a same fish species. The net margin is gross return minus total production costs. Unit net margin or per kg net margin is net margin divided by quantity of fish produced. It allows the comparison of production systems raising different fish species. The formula below was used:

Gross return = Quantity of fish produced (kg) x unit price of fish; variable costs = inputs (feed) + labor + small tools (material lasting no more than one year); fixed costs = depreciation of equipment (infrastructure + material lasting more than one year) + salaries of permanent labor + overheads; gross margin = gross return – variable costs; net return (NR) = gross return – total costs (TC); profit rate (%) = 100 × NR/TC

Overall, the main indicators of the financial performance of each production system include the per kg gross margin, per kg net return, and mostly the profit rate. The most critical and ubiquitous indicator of financial profitability is the profit rate. It is the net return (or profit) (NR) divided by total production costs (TC). It is usually expressed in percentage (%) of total costs and enables the comparison of production systems using either the same or different fish species, or different farms using different combinations of fish species.

RESULTS AND DISCUSSION

Comparison of LWP and AGT's fish farming profitability

The results in Table 3 show that unit gross margin (FCFA/kg) from *Clarias* production in LWP is 31.1% greater than in AGT. However, it is worth recalling that the two types of infrastructure do not give the same possibility for fish production, that is, the amount to be harvested at a time which depends on the quantity of fingerlings supplied and feeding sources. In the ponds (LWP), fishes feed themselves with living organisms (animal and vegetal planktons) available in the river water, in addition to the feed supplied by the fish farmer. In the case of AGT, only the feed is available to them, while water is artificially supplied with usually high oxygenation constraints related to water rotation, oxygen equipment and power supply. In contrary to LWP, fishes raised in AGT also use their energy not only for growth but also for breathing, while their mobility is restricted, thereby limiting their growth and weight gain.

Discussion on the financial profitability of Clarias fish farming

The net return per kg obtained from farming with LWP is higher than with AGT. Likewise, the profit rate obtained with LWP is 57.67%, which is ten-fold that with AGT (Table 3). The profit rate in the latter case is by far lower than the 20% interest rate charged on loans from commercial banks in Benin. This indicates that only LWP fish farming provides an adequate cost recovery and a substantial capital remuneration.

The message from these results is that modern is not always profitable, as the theory of industrialization would pretend. Considering the growing demand for fish in Benin and Nigeria, and the contrasting high level of poverty and malnutrition among fisheries communities in Benin (Sohou et al., 2009), the above finding of the study provides an argument for promoting investment support to these communities for Clarias fish farming in ponds (LWP) along lakes. Indeed, such an action will enable the production of large quantities of fish to meet domestic needs in quality protein and for sale, especially in Nigeria where this fish species is particularly appreciated, and to break the vicious circle of huge fish imports.

However, although Clarias farming in LWP is more profitable than in AGT, the latter may be worth a promotion if, and only if, local substitutes to imported feed become available. Indeed, feeds represented 72-74 and

Table 3. Complete budget of 6-month LWP and AGT farming of *C. gariepinus.*

Items	AGT	LWP
Quantity of fish (kg)	36	720
Yield (kg/are)		360
Gross Return (FCFA)	54000	1080000
Variable costs (FCFA)	36250	614500
Inputs	35250	579500
Labour		35000
Small tools	1000	
Fixed costs	14834	70500
Gross margin (FCFA)	17750	465500
Gross margin per kg (FCFA)	493.05	646.52
Net return or profit* (FCFA)	2916	395000
Net return per kg (FCFA)	81	549
Profit rate** (%)	5.70	57.66

*In normal business, capital cost (interest on bank loans and loan administration costs), taxes and other fiscal dues should be deducted from the net return to get the profit. **Profit rate = 100*(profit/total cost); Source: The experiment.

48-58% of total production cost, respectively in monoculture and polyculture in Bangui neighborhoods[6]. Ike and Chuks-Okonta (2014) found that they weigh 79% in total cost in Burutu and Warri South areas of Delta State, Nigeria. In the current case, imported feeds accounted for 50% of total cost, yet with profit rate (57.7%) far lower than the 87.6-163.6% observed in Bangui several years ago[7]. Kasozi et al. (2014) also found a comparable profit rate of 69% in West Nile agroecological zone of Uganda. Alternatively, substantial profits could be derived also from AGT fish farming when local feeds combining animal husbandry by-products and living organisms such as tadpole are used (FAO, 1991). This type of fish farming, which requires less investment than LWP, would be then profitable for small farmers and lead to artisanal fish farming development. Moreover, considering the easy mobility and low space fitting of AGT, its dissemination among urban farm households can therefore be envisaged for addressing unemployment among the youth. Yet, it is inappropriate for large-scale commercial production because of dis-economies of scale (PROVAC, 2013, 2014).

Conclusion

The paper aimed to shed a first light on fish farming profitability in Benin, with the aim of appropriately directing investment support towards more suitable fish production systems depending on investment capacity and locations (urban, rural valleys, lakes and rural upland) of targeted farmers. The experimental assessment of Clarias' production systems in Benin revealed that lake water-fed pond fish farming was very profitable and may be promoted among village fishermen's cooperatives or young rural entrepreneurs. Considering that fishermen's cooperatives are not yet very well developed, NGOs and the government should provide the dedicated group management training and financial support to fishermen to enable them face the high initial investment costs of ponds' installation. On the other hand, AGT fish farming was by far less profitable due to high costs of imported feeds and electricity. However, small urban farm households may be advised to use it for meeting their family needs in proteins. AGT is more affordable to medium-scale fish farmers and may still be promoted for commercial fish production when cost-effective local substitutes to imported feeds become available. There is a need to install quality feed production enterprises to promote both fish production systems towards sustainability, food security and economic development. The study confirms that modernizing fish farming is not only a matter of modern infrastructure but also of feed quality depending on feed type (natural aquatic or non-aquatic organisms vs. manufactured feed, nutritional density) and feed affordability depending on sources (locally produced vs. imported).

However, the study's limitation points to the fact that the results would have had stronger significance if they are derived from a sample of fishermen using both types of infrastructure. Further research is therefore needed in that respect, as well as on farmers' perceptions of the

[6] FAO Archive on the breeding of African catfish *Clarias gariepinus*.
[7] FAO Archive on the breeding of African catfish *Clarias gariepinus*.

proposed technologies.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Economic profitability and risk analyses of improved sorghum varieties in Tanzania

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This study uses survey data collected in 2012/2013 farming season to determine the net-returns and utility-efficient farm management practices for improved sorghum varieties adopted by small-scale farmers in Tanzania. The reference farm management practice was using JEMBE (handhole) for land cultivation and growing local varieties (landraces). Other farm management practices included using ox-plough for land cultivation with or without applying manure for soil amendment, and using JEMBE for land cultivation with or without applying manure. Improved sorghum Varieties included Tegemeo, Pato, Macia, Wahi, Hakika, Mtama-1, and Sila. We used simulation and bootstrapping to estimate yield distributions and net returns and stochastic efficiency with respect to a function to complement first and second degree stochastic dominance analyses to determine varieties and farm management practice that reduce production and price risk. Under profit maximization and risk reduction assumptions, main results show that Macia and Mtama-1 varieties have high mean yield and low yield variability. Even under low inputs and extreme risk averse farmers, Macia and Mtama-1 were superior choices. Value addition activities increased price offered to farmers, which also reduced price risk.

Key words: Economic profitability, risk analysis, sorghum, stochastic dominance, Tanzania.

INTRODUCTION

Sorghum (*Sorghum bicolor* L. Moench or Mtama in Swahili) is one of the five most important cereal crops in the world. It has adapted to a wide range of soil conditions, ranging from sandy to water logging and to residual moisture, and from salinity to extremely low soil pH. Because of its broad adaptation, the Association for Strengthening Agricultural Research in East, and Central Africa (ASARECA) categorize sorghum as one of the climate change ready crops (Kimenye, 2014). The great advantage of sorghum is that it can become dormant under adverse conditions and can resume growth after relatively severe drought. Early drought stops growth before floral initiation and the plant remains vegetative; it will resume leaf production and flower when conditions again become favorable for growth. Late drought stops leaf development but not floral initiation. Rohrbach et al.

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(2002) show that sorghum is the second most important staple food after maize, which benefits more that 80% of Tanzanians. The crop is predominant in the central plateau of Dodoma and Singida regions. Other regions with significant sorghum production include Tabora in Western Zone; Shinyanga, Mwanza and Mara in the Lake Victoria region. Regions in the Northern Tanzania (Arusha, Kilimanjaro, and Manyara) are increasingly integrating sorghum in the farming system to mitigate and adapt to the consequences of climate change and to address recurring food shortages resulting from crop failures.

Almost 85% of the sorghum produced in Tanzania is for food consumption at the household level. Non-food industrial use is relatively underdeveloped. Depending on available rainfall, production is occasionally less that demand. Over the last 20 years, average sorghum grain yield in Tanzania have ranged from 442 kg/ha (in 2003) to 1,310 kg/ha (in 2010) (Kombe, 2012). The low average sorghum yield is attributed to low soil fertility, bird damages, Striga weed infestation, use of cultivars with low yield potentials, and socio-economic factors that constrain farmers' access to improved seed. There is a potential of increasing yield from their current low levels through the adoption of improved varieties and improved soil fertility and water management practices (Mgonja et al., 2005). While sorghum utilization is mostly for food purposes, composite flour of sorghum /wheat/cassava produces several value-added products for home consumption and marketing. Sorghum grains are also a source of industrial starch and are important component of processed animal and poultry feeds. Currently, the brewery industries in Tanzania are using sorghum flower to produce lager beer and non-alcoholic drinks and using starch from sorghum for fermentation and bioenergy drink production (Rohrbach and Kiriwaggulu, 2007).

Sorghum research and development activities in Tanzania, trace back to the early 1980s. In that period, the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) started collaborating with the Tanzania Ministry of Agriculture through the Department of Research and Development (DRD) as well as some Non-Governmental Organizations (NGOs). These entities collaborated in developing and evaluating sorghum varieties targeting the dry lowlands. Early efforts led to the release of three sorghum varieties namely Tegemeo, Pato, and Macia in 1978, 1997 and 1998, respectively (Mgonja et al., 2005). Two other varieties released in 2002 are Wahi and Hakika. Another variety released by ICRISAT and DRD in 2008 is NARCO Mtama-1 (or Mtama-1). In addition, a private seed company, Seed Co Tanzania Limited (SEEDCO), released Sila variety in 2008 (Monyo et al., 2004; MAFC, 2008).

The sorghum varieties selected by ICRISAT's and its partner are essentially drought tolerant crops with optimal utilization for human consumption, optimal value adding to produce animal feed and for baking and brewing. The crop is common among agropastoralists in Central and Eastern Tanzania where utilization of crop residues as animal fodders is also important. Furthermore, Tanzania is experiencing a dramatic agricultural policy changes and creating a favorable environment for accessing agricultural inputs. The sorghum seed subsidy scheme was started in 2010 to mitigate the constraint of improved seed adoption due to lack of certified seeds. This scheme is also allowing farmers to have access to improved sorghum seed at lower price. In the past, the modes of sorghum utilization were limited to food consumption at the household level. Due to several marketing initiatives, sorghum is entering the non-food and value adding markets as demanded by the baking, brewery, and animal /poultry feed industries. These value-adding activities require varieties with specific attributes in term of grain quality and other specific characteristics. For example, Macia, Tegemeo, and Mtama-1 varieties meet the specifications for brewing lager beer. Research and extension effort is geared towards linking the small-scale sorghum producers to this new market (Kombe, 2012).

One of the main objectives of this study was determining the economic profitability of improved sorghum varieties among small-scale farmers in the main farming systems in Central, Western, and Northern Tanzania. Economic profitability is particularly important issue for small-scale sorghum producers, as most sorghum production occurs in arid and semi-arid regions that have high rainfall variability. Breeding programs for improved sorghum varieties aim to reduce production risk by selecting drought tolerance and early maturing traits. Profitability analysis and risk assessment are both vital in determining potential for adoption and diffusion of selected varieties. We use stochastic dominance and stochastic efficiency with respect to a function (SERF) to test if improved sorghum varieties increase profitability, reduce production risk, or both. As demonstrated in Bryant et al. (2008) and Shankar et al. (2007), risk assessment using stochastic approach allows for comparison across farmers who plant different varieties and provide valuable insight from a single season of data. Results from this study will allow ICRISAT and DRD to test the validity of its new research strategy, and to identify efficient mechanism and adoption pathways to other mandate crops.

The format of this paper is as follows. The next section of this paper reviews recent literature on economic profitability and stochastic dominance analyses. The subsequent sections outline data collection methods and present data summary, results, and conclusions from the study.

Economic profitability and risk analyses

Most agricultural technologies are technically feasible but this is not a necessary condition for adoption by small-scale farmers. Profitability of available agricultural technology is a propelling factor during the adoption process. Therefore, it is important for research and extension programs to determine the profitability of new or improved agricultural technology under existing small-scale farmer's conditions. One approach is using partial budgeting, which is a simple and very helpful economic and management tool to use when determining the profitability of agricultural technologies at the farm level. Results from partial budgeting are useful in terms of comparing the costs and returns associated with small, specific, and limited changes in farm activities during the adoption process. The process involves tabulation of expected gains and losses from the adoption of new farming methods or practices. Therefore, a partial budget list consists of only those items of revenue and expenses that change after adoption of improved sorghum varieties. These measures include change in returns and costs associated with limited resources. The results provide a limited assessment of risk and suggest a range of prices or costs at which new farming methods or practices are profitable (Doupéa and Lymberyb, 2002).

The partial budgeting process answers the question "what would happen to farm profit if adoption occurs?" Results from the process help researchers, extension agents, and farmers to evaluate the economic effect of incremental changes of certain resources associated with the adoption process (Pitcher et al., 2013). With capital constraint, as is common under small-scale agriculture, higher returns may not be attractive if they require very much higher additional costs. For example, adoption of new agricultural technologies typically requires adopting a package of complimentary inputs such as inorganic fertilizers and small-scale farmers always consider these additional costs in their adoption decision-process. Thus, it is necessary to compare the extra (or marginal) costs with the extra (or marginal) net benefits by estimating marginal rate of return (MRR) that measures the increase in net profit associated with each additional unit of cost. This will determine if the new technology costs more than the farmer's present technology or if the new technology yields more returns than the present one for a comparatively higher cost (Kaliba et al., 2000).

Partial budgeting can therefore be a great tool for looking at a change that only affects one or two areas of production practices. However, this tool also has its limitations. If the results are positive, a partial-budget analysis does not tell you if it occurs because of a change in hard numbers, such as the cost of improved seeds, or soft numbers, such as an increase in the rate of gain. Partial budgeting looks only at one area and does not address the question of whether the change was the best use of limited resources (Swinton and Lowenberg-Deboer, 1998). Moreover, partial budgeting results are not additive and do not look at other areas of the farm activities that may change and affect the budget. Employing sensitivity analysis mitigates some of the limitations as noted by Saltelli et al. (2000) and Boyer et al. (2011); however, results are not good at projecting the future. Sensitivity analysis is only useful when attempting to determine the impact of uncertainties of a variable on adoption outcome. For example, sensitivity analysis could determine the impact of yield, input, and output prices variability on profit and breakeven point.

While partial budgeting is a first step in risk assessment, the procedure cannot make a robust comparison for two distributions. In risk assessment, it is important to check whether profitability distribution of advocated agricultural technology always dominates the existing technology. This is because, for sorghum producers, income and yield stability is an important aspect of the adoption process (Belaya and Bewket, 2013). Profitability and yield distribution of improved varieties must dominate local varieties especially during low rainfall season. This is a fundamental concern for a farmer who is choosing among risky alternatives. To address this issue, Stanger et al. (2008) suggest using stochastic dominance analysis, a graphical tool that checks whether the profitability or yield of improved varieties dominates local varieties under different management practices. That is, improved varieties are always superior under all circumstances. If applied, the technique identifies conditions under which one risky outcome would be preferable to another (Lambert and Lowenberg-DeBoer, 2003).

Essentially, stochastic dominance analysis involves comparing cumulative distribution functions (CDF) of economic profitability measures or yields of improved varieties and local varieties under different management scenarios. The basic assumption is that one or the other technology must be adopted and not a convex combination of both (Hardaker et al., 2004). Here x is a random variable representing each level of net returns, or yield for crop management alternatives such that $f(x)$ is the probability density function (PDF) associated with adoption of improved seeds and $g(x)$ is the probability density function associated with non-adoption (growing local/traditional varieties). Under the first-degree stochastic dominance (FSD) conditions and using the assumption that more is preferred to less; implies that for $f(x)$ to dominate $g(x)$, the cumulative probability of distribution (CDF) of $f(x)$ must always lie on or to the right of the cumulative probability distribution (CDF) of $g(x)$. In other words, improved crop varieties always outperform local varieties (in terms of net returns or yield) and the two distributions never cross, which may not be true (Barrett et al., 2004).

The second-degree stochastic dominance (SSD) invokes the assumptions that a farmer has both positive and diminishing marginal utility. These assumptions mean that for $f(x)$ to dominate $g(x)$, the area under the CDF of $f(x)$ must be smaller than the area under the CDF of $g(x)$. This assumption allows the two-cumulative distribution to cross if the difference in the area before they cross at low distribution is relatively smaller compared to the difference in the area after they cross at upper distribution of the CDF (Barham et al., 2011). This implies that adoption does not necessarily reduce the probability of very low-net returns or yield outcomes but improved varieties dominate traditional varieties and therefore reduce production risk especially for small-scale farmers who are risk averse.

Comparatively, the FSD simply assumes that producers prefer higher net returns (higher yield) to lower net returns (lower yield), and that decision-makers have absolute risk aversion ($r_a(x)$) with respect to net return or yield. The absolute risk aversion coefficient (ARAC) is estimated as $r_a(x) = -U''(x)/U'(x)$, which represents the ratio of the second and first derivative of the farmer's utility function (Pratt, 1964) and the relative risk aversion coefficient ($r_r(x)$) is ($r_r(x) = xr_a(x)$). The SSD, is therefore a more restrictive approach and assumes that decision-makers are risk averse by restricting the bounds of absolute risk aversion with respect to x to be between $0 \leq r_a(x) \leq +\infty$ (Hardaker et al., 2004). The drawback is that given the wide range of absolute risk aversion, the alternative(s) that represent the preferred choice within a given bound can still be too large to be easily manageable (King and Robison, 1984). Other inherent limitations of stochastic dominance are as summarized in Bryant et al. (2008).

Anderson (1974) and Meyer (1977) proposed stochastic dominance with respect to a function (SDRF) as an alternative to FSD and SSD. They propose limiting the absolute risk aversion coefficients between arbitrary lower and upper bounds such that $r_l(x) \leq r_a(x) \leq r_u(x)$, where r_l and r_u are chosen by an individual conducting the research. The ranking of risky scenarios is defined for all decision makers whose lower absolute risk aversion function lies anywhere between lower and upper bounds $r_l(x)$ and $r_u(x)$, respectively. These lower and upper bound functions can be any function of x, although in practice these bounds are often constants with no other assumption on risk aversion (Meyer et al., 2009). The method has stronger discriminatory power than FSD and SSD, because of the introduced tighter risk aversion bounds. The SDRF approach eliminates inefficient alternatives by determining the risk aversion measure $r_a(x)$ that lies between the lower and upper bounds, which minimizes the difference in expected utility ($E(U(x)_F)$-$E(U(x)_G)$), from alternatives $f(x)$ and $g(x)$. When the expected utility difference is non-negative, then, $f(x)$ is preferred or indifferent to $g(x)$ by all decision makers, and elimination of $g(x)$ from a set of alternatives is appropriate. When the value for the expected utility difference is negative then, the decision maker with risk aversion measure $r_a(x)$, prefer $g(x)$ to $f(x)$ and alternative $g(x)$ is not eliminated (Meyer et al., 2009).

However, SDRF may often results in ambiguous rankings and the results tend to depend on the selected value of the lower (r_l) and upper (r_u) bounds. Barham et al. (2011), Hignight et al. (2010) and Hardaker et al. (2004) suggest using stochastic efficiency with respect to a function (SERF) to complement stochastic dominance analysis while taking advantages offered by SDRF. Using risk aversion bounds, SERF works by identifying utility efficient alternatives for ranges of risk attitudes and not by finding (a subset of) dominated alternatives. Therefore, SERF partitions alternatives in terms of certainty equivalent (CE) as a selected measure of risk aversion that varies over a defined range. Based on the specified utility function, CE is the amount of net returns necessary to make the decision-maker (the farmer) indifferent to the available alternatives.

While both SDRF and SERF compare risky prospects for a range of degrees of risk aversion between specified lower and upper bounds, SERF imposes an additional restriction by holding the measure of risk constant as the level of outcomes (x) changes; thereby, potentially contracting the efficient set. The procedure provides a more restrictive approach to compare risky alternative by evaluating technology dominance across a wide range of plausible risk preferences. The technique allows ordering alternatives agricultural technologies in terms of CE values within a range of risk-aversion coefficients. The method does not attempt to pinpoint risk aversion levels elicited by experimentation or estimation to categorize alternatives; rather, it takes risk aversion levels as given and presents a class of rankings based on categories of decision makers within ranges of risk aversion for a given utility function (Meyer et al., 2009).

For SERF, certainty equivalents are estimated assuming different risk aversion coefficients as outlined in Hardaker et al. (2004). For a small-scale farmer, a reasonable agreement is using a negative exponential utility function as it has a concave slope, which characterizes risk-averse farmers (Babcock et al., 1993). The relationship among the utility function $U(x)$, the absolute risk aversion coefficient ($r_a(x)$), and the relative risk aversion coefficient ($r_r(x)$) is as explained above. For a sample of size n from a risk alternatives x (different farm management practices) with i outcomes (yield of different varieties or net-returns from different varieties), certainty equivalent (CE) is estimated as follows:

$$CE(x, r_a(x)) = -\frac{1}{r_a(x)} \ln\left\{\left(\frac{1}{n}\sum_i^n \exp(-r_a(x)x_i\right)\right\} \quad (1)$$

Anderson and Dillon (1992) suggests using relative risk aversion that range from 0 for risk neutral to 4 for highly risk averse farmer. The $r_a(x)$ are obtained by dividing the range of $r_x(x)$ with the estimated expected returns from the reference technology. The graphical relationship between the CE and the absolute risk aversion coefficients depicts the dominance of one technology relative to another technology, using the reference technology as a benchmark. The decision rule for SERF is to rank the risky alternatives (within the decision-makers' specified risk aversion coefficient) from the most preferred (the highest CEs at specified levels of risk aversion) to the least preferred (the lowest CEs at specified levels of risk aversion). The risk premium is the difference between the CE of dominated/inferior technology and CE of the dominant technology.

METHODOLOGY

Source of data

The data for this analysis is from a sampling survey conducted by Selian Agricultural Research Institute (SARI), Arusha, Tanzania in collaboration with ICRISAT, Nairobi, Kenya. The main author developed the structured questionnaire used in the study. The questionnaire was reviewed during a two-days enumerator-training workshop organized by the main author in May 2013. Twenty-five extension agents working in major sorghum farming systems and three scientists from ICRISAT participated in the workshop. After the workshop, the questionnaire was pretested in Singida Rural (Central Tanzania) and Rombo Districts (Northern Tanzania). Results and problems arising from questionnaire pretesting created the guidelines in refining the final survey instruments used in the study, that is, the village level instrument and the household level instrument.

The selection of participating districts from five regions (Dodoma, Kilimanjaro, Manyara, Singida, and Shinyanga) accounted the intensity of sorghum production and importance of sorghum in the farming system. The districts included Iramba, Singida Rural, and Manyoni districts (Singida Region), Kondoa District (Dodoma Region), Babati District (Manyara Region), Rombo District (Kilimanjaro Region), and Kishapu District (Shinyanga Region). From each district, two Wards (and one village from each ward) were randomly selected from these seven districts[1]. The sample includes fourteen Wards and fourteen villages. To create a representative sample of adopters, it was predetermined that 60% of responding households would be that planted at least one improved sorghum variety during the 2012/13 farming season. For statistical analysis, the sample size per village was predetermined to be at least 50 households. About 822 households participated in the survey, of which 505 were adopters (61.44%) and 317 nonadopters (38.56%). Previously trained enumerators collected the data and respondent was a knowledgeable farmer at the household level.

The village-level survey instrument solicited information on availability of extension and marketing services and supportive agricultural infrastructures at the village level. The respondents were a group of informants including village leaders, extension agents and government and NGOs representatives. The same group estimated labor input and cost for the sorghum enterprise based on their experience. This method was preferred to reduce the size of the questionnaire and recall bias on input use. The household-level instrument has several sections to collect data that linked the households to the village identifiers. Other sections recorded data on price, yield, and other variable costs associated with each stage of sorghum production from land cultivation to transportation and storage activities.

Data analyses

To conduct partial budgeting and stochastic dominance analysis the following facts were considered. Local varieties and using JEMBE (handhole) for land cultivation was the reference farm management practice. In the study area, the main farm management practices that influenced yield included the use of ox-plough for land cultivation and application of farm yard manure on sorghum field. Therefore, farm management technologies include using ox-plough for land cultivation and applying manure for soil amendment, using ox-plough for land cultivation but without manure application, using JEMBE for land cultivation and applying manure, and using JEMBE for land cultivation without manure application. For partial budgeting, incremental costs are from weeding frequency, and bird scaring. Other costs were determined based on land preparation methods and type of varieties planted. Very small farmers (less than 1%) reported using inorganic fertilizer and chemicals such as herbicides, fungicides, and insecticides. These variables were therefore not included in partial budgeting and economic analysis. Improved sorghum varieties were Tegemeo, Pato, Macia, Wahi, Hakika, Mtama-1, and Sila. All other local varieties were grouped as local varieties/landraces.

To increase variability and statistical tractability, variables used in partial budgeting and stochastic dominance analysis were generated through random simulation of observed variables using a bounded normal distribution function (Trautmann et al., 2014). Particularly, stochastic features were incorporated by utilizing the observed minimum and maximum values and estimated sample mean and the standard deviation to generate a random variable with 1,000 observations. The stochastic depended variables included yield and price received by farmers, price of seed, and cost of labor. The generated random variables were used to estimate revenue, cost, and net returns. Bootstrapping (Efron, 1979) with replacement was also conducted to estimate the distribution of yields and net-returns for each variety in each of the farm management practice. In this case, farmers are profit maximizer and face stochastic output and input price. Profit distribution from each crop variety is modelled from the following profit equation:

$$E(NR) = E(P_o)E(Y) - Q_s E(P_s) - Q_l E(w) - FC \quad (2)$$

In Equation 2, $\boldsymbol{E(.)}$ is expectation operator, $\boldsymbol{NR}$ is net-returns, $\boldsymbol{P_o}$ is output price, $\boldsymbol{Y}$ is yield, $\boldsymbol{Q_s}$ is quantity of seeds, $\boldsymbol{P_s}$ is price of seeds and $\boldsymbol{Q_l}$ is quantity of labor, $\boldsymbol{w}$ is wage, and $\boldsymbol{FC}$ is fixed cost. For comparison purposes, fixed cost is constant across varieties within a given farm management practice and drop-out during the analysis.

Performing SSD and FSD required generating empirical cumulative density functions (ECDFs) representing stochastic variables from each farm management practice. When generating ECDFs for continuous random variables, there is a potential of producing negative values for the distribution function. To avoid negative values the realized value of each stochastic variable formed irregularly spaced grid. This allowed producing a continuous distribution function by linear interpolation over vertices of that grid; that is, over the observed lowest and highest values of the variable. Certainty Equivalent for each improved sorghum variety (and for each management practice) was estimated using Equation (1). The $\boldsymbol{r_r}(x)$ ranged from 0 for risk neutral to 4 for highly risk averse (Anderson and Dillon, 1992). The $\boldsymbol{r_a}$ (x) were obtained by dividing a range of $\boldsymbol{r_r(x)}$ with estimated value of expected (mean) yield or net-returns of the reference technology. Generally, the expected value of a continuous random variable ($\boldsymbol{x}$) that is bounded between $\boldsymbol{a}$ and $\boldsymbol{b}$ and with the probability density function $\boldsymbol{f_x}$ can be estimated through numerical integration as follows:

$$E(x) = \mu_x = \int_a^b x f_x(x)dx \quad \text{for } a \le x \le b. \quad (3)$$

[1] Tanzania is administratively divided into Regions, Districts, Wards, and villages. Therefore, the Village is the lowest administrative unit.

Table 1. Land allocation to sorghum varieties for the 2012/13 farming season.

Variety	N	Sorghum varieties		Total acreage		Proportion of land to improved seeds	
		Hectare	Std. Dev	Hectare	Std. Dev	Mean	Std. Dev
Adopters (N=505)							
Tegemeo	96	0.65	0.10	2.67	1.45	0.33	0.25
Pato	46	0.81	0.74	2.78	0.96	0.32	0.27
Macia	278	0.94	0.52	1.91	0.54	0.64	0.53
Wahi	35	0.75	0.56	2.77	1.06	0.34	0.25
Hakika	32	0.83	0.13	1.62	0.54	0.61	0.36
Sila	22	0.72	0.38	2.27	0.91	0.42	0.3
Mtama-1	71	0.65	0.24	2.37	0.69	0.34	0.28
Nonadopters (N=317)							
Langalanga	55	0.85	0.18	2.82	0.84	0.48	0.29
Other cultivars	273	0.75	0.14	2.67	0.85	0.35	0.26

N is the numbers of households, and St. Dev is the standard deviation.

In Equation 3, $\boldsymbol{E(x)}$ is the expectation operator. One way to proceed is to first create two data vectors of $\boldsymbol{x}$ and associated geometric probabilities $\boldsymbol{f_x(x)}$ then multiply and sum the product. We developed several scripts, which were implemented in R environment (R Core Team, 2016) that were efficient in estimating Equations 1 through 3.

To compare different management practices, we used the Welch's t-test (Welch, 1947) to perform equal mean test. The test was performed at 5% level of significance. The test is a two-sample location test used to test the hypothesis that two populations have equal means and accounts for unequal variance. Test of significance for the hypothesis is that the mean difference is equal to zero and the alternative hypothesis is the true difference in means is not equal to zero. We also used the Levene-test (Levene, 1960) at 5% level of significance, which is used to test if two or more samples have equal variances. The Levene-test tests the null hypothesis that the population variances are equal (that is, homogeneity of variance or homoscedasticity). It is an alternative to the Bartlett test (Bartlett, 1937); however, the Levene test is less sensitive than the Bartlett test to data that are not normally distributed. The Bartlett test has a better performance for data that come from a normal or nearly normal distribution. For this study, simulations, bootstrapping, graphics, and data analyses were produced and conducted using user defined functions in R software (R Core team, 2016). The data and R scripts used in the study are available upon request.

RESULTS AND DISCUSSION

Stochastic partial budgeting and marginal analysis

Table 1 shows land allocation to sorghum production by sample households. In Table 1, total acreage is the total land allocated to cereal production in 2012/2013 farming season, with farmer primary growing sorghum varieties, but also maize, different types of legumes, and other crops. The estimated average land allocated to cereal production was 2.43 ha with standard deviation of 0.87 ha. Land allocated to cereal production by adopters and non-adopters were 2.34 and 2.75 ha with the standard deviations of 0.88 and 0.85 ha, respectively. The t-test results indicate that non-adopters had more land allocated to cereal production compared to adopters at 1% significance level. From Table 1, on average, adopters allocated 43% of the land to improved sorghum varieties with a standard deviation of 32%.

Results in Table 1 also show that majority of farmers cultivated a single variety rather than a combination of different varieties. The widely adopted improved sorghum variety was Macia. About 55% of the adopters planted the variety. Tegemeo variety was second as was planted by 19% of adopter households and Mtama-1 was third, which was planted by 14% of the adopter group. Land allocated to improved sorghum varieties was high for adopters of Macia and Hakika varieties that respectively allocated 64 and 67% of the cultivated land to the two varieties. Hakika and Macia adopters have relative smaller land holdings in terms of land allocated to cereal production in the 2012/2013 farming season. For adopters, farmers with small land holding, depended more on improved sorghum varieties for cereal production compared to other farmers.

The estimated labor costs for important sorghum production activities are presented in Table 2. The highest cost was on manure application followed by land cultivation using ox-plough, bird scaring, and transportation and other activities. Other high cost activities include land preparation using JEMBE (hand-hole), weeding in broadcasted plot, weeding in line-platted crop, and harvesting and threshing. In the study are, differences in farming methods include using JEMBE or ox-plough in land preparation, using line planting or broadcasting of seeds that also influence manure application and weeding cost. Therefore, using JEMBE and ox-plough as land preparation tools are major technical differences between the farmers. The benefits

Table 2. Estimated labor cost for main farm activities in the study area (Tshs/ha).

Activity	Mean	Standard deviation
Land cultivation using JEMBE (hand-hole)	115,541	83,484
Land cultivation using ox-plow	138,722	62,243
Primary and secondary tillage	44,425	27,209
Seed broadcasting	15,187	4,571
Line planting	38,259	21,775
Fertilizer broadcasting	14,858	4,685
Manure application/broadcasted plot	179,421	171,447
Manure application/line planted plot	50,810	64,292
Weeding/line planted plot	107,711	47,689
Weeding/broadcasted plot	112,020	69,960
Herbicide and pesticide application	43,649	28,494
Bird scaring	132,705	100,372
Harvesting and threshing	85,375	37,535
Transportation and others	122,562	90,448

Tshs is Tanzania shillings. The average exchange rate was $1 per 1,200 Tshs in 2013.

Table 3. Sample estimates on average yield, price, and cost variables in the study area.

Variable	Tegemeo	Pato	Macia	Mtama1	Wahi	Hakika	Sila	Local
Using ox-plough for land cultivation (N=321)								
Yield with manure	1,889	2,788	2,992	2,820	2,614	2,609	2,386	1,570
Standard deviation	187	203	256	274	197	299	151	76
Yield without manure	1,259	1,394	1,580	1,410	1,307	1,087	1,193	654
Standard deviation	312	338	466	498	359	499	301	138
Using JEMBE technology (N=501)								
Yield with manure	1,962	2,453	2,528	2,482	2,396	2,150	2,290	1,046
Standard deviation	163	210	249	210	221	275	217	66
Yield without manure	1,117	1,115	1,264	1,128	1,198	1,075	1,145	523
Standard deviation	326	350	453	350	442	458	362	110
Other variable								
Sorghum price	562.1	473.0	562.5	651.9	520.6	525.6	531.8	612.5
Standard deviation	29.39	30.84	31.25	42.00	65.8	68.15	67.14	57.11
Seed cost	12,381	10,690	8,221	10,231	9,200	9,150	15,000	9,622
Standard deviation	279	264	289	177	257	393	147	236

Standard deviations are for respective variables. The estimate is from sample households. Yields are in kg/ha, price is in Tshs/kg, and seed costs is in Tshs/ha.

of using ox-plow are that the farmer has time to plant and weed the crops early thus improving yield and productivity. From farmer's experience, in sorghum fields where JEMBE is a tool for land cultivation, usually the yield is less when compared to sorghum fields that where ox-plowed. In addition, farmers who use JEMBE for land cultivation has higher incidence of weeds and have to weed the field twice to control weed infestation. The weeding cost for JEMBE technology is therefore 50% higher compared to the ox-plow technology.

Table 3 shows average yield and price, and other cost as reported by sample households. In the table, for each farm management practice, yield of all improved varieties were relatively high compared to local varieties. The yield of improved sorghum varieties were as low as 1,087 kg/ha for ox-plough technology and 1,075 kg/ha for JEMBE technology alone (Hakika variety) to as high as 2, 992 kg/ha (Macia variety with ox-plough with manure application). This is compared to low yield of 523 kg/ha for local varieties under JEMBE without manure application. The yield of local varieties increased substantially with manure application to about 1,046 and 1,579 kg/ha for JEMBE with manure application and ox-plough with manure application applications, respectively. For improved sorghum varieties, Macia recorded the highest yield in all farm four management practices, followed by Mtama-1 for ox-plough with and without manure application and JEMBE with manure application. Hakika recorded the lowest yield for ox-plough technology and Tegemeo for JEMBE technology. For JEMBE without manure application, the second-high yielding improved variety was Wahi. Average yield of Tegemeo variety was related low compared to other varieties. Despite having lower yield, local varieties have small standard deviation, which implies lower risk in terms of yield variability. For improved varieties, Hakika has the largest standard deviation for both technologies and Tegemeo has the lowest standard deviation.

The farmers also reported quantity of seed sown, area planted, and unit price that were used to estimate seed cost per hectare as shown in Table 3. The seed cost ranged from 8,221 Tshs/ha for Macia variety to 15,000 Tshs/ha for Sila variety. Seed price usually depended on distribution channel, specifically on transportation cost. Sila variety is distributed by Seed Co Limited based in Zimbabwe. Other varieties are produced and distributed by seed companies/institutions based in Tanzania. Differences in distribution cost may account for the high price of Sila variety seeds. The results in Tables 1, 2, and 3 indicate that majority of farmers prefer high yielding varieties (Macia and Mtama-1) followed by varieties with low yield variability (Tegemeo). Results in Table 3 also show that price received by farmers varied across varieties, attributable to market demand and taste and preferences. Farmers growing Mtama-1 received the highest price (652 Tshs/kg) followed by Macia (562.50 Tshs/kg) and farmers growing Pato variety received the lowest price of 473 Tshs/kg. Mtama-1 grains are suited for food and brewing due to high percent extract (above 82%) and low nitrogen contents (less than 2.0%). The grain has no tannin, therefore can be used in poultry feed production. Macia grain utilizations include multiple food uses such as porridge, in composite flour for bread (20% sorghum, 80% wheat) and in biscuits and pasta (50% sorghum, 50% wheat flour). Also, Macia grains are suitable in the production of livestock feed, especially poultry feed. Mtama-1 and Macia grains have alternative market channels that are increase demand and therefore price received by farmers. Also, local varieties received higher price (612 Tshs/kg) when compared to other improved varieties. For improved varieties and for farmers producing at the subsistence level; taste and preference of consumers determine price received. In the study area, local varieties are superior in term of the two attributes.

Estimated net-returns by land cultivation method and manure application are as shown in Table 4. Net-returns is the difference between revenue and total cost and is calculated based on per-hectare basis. Revenue is estimated as a product of yield and price received by farmers after accounting for variability in both yield and price through Monte-Carlo simulation (Equation 2). In Table 4, labor cost was estimated using the data reported in Table 2, basing on farm activities applicable to each farm management practice also considering variability through Monte-Carlo simulation. Revenue (yield x price) and total cost (seed cost plus total labor cost) were obtained through stochastic simulation and budgeting. Marginal return is the percent increase in total revenue relative to percent increase in cost when moving from growing local varieties with JEMBE as a main method for land cultivation (reference technology) to other farm management practices. Notice that large variation in net returns occurs between farm management practices and varieties primarily due to yield, farm get price, and differences in labor use.

Except for net-returns from ox-plough with manure application, the landrace/local varieties recorded negative net-returns (Table 4). Moving from JEMBE alone to other technologies, however, minimized losses. Other varieties that registered negative net-returns were Pato variety under JEMBE without manure application and Hakika variety under ox-plough with manure application. Results in Table 4 also show that Macia and Mtama-1 varieties performed better in generating high net-returns compared to other improved Varieties. Net-Returns ranged from 159,000 Tshs/ha (JEMBE without manure application) to 1,246,000 Tshs/ha (Ox-plough with manure application) for Macia. Similarly, net returns for Mtama-1 ranged from 84,000 Tshs/ha to 990,000 Tshs/ha. These results can be attributed to relative high yield recorded by the two varieties and relatively high price received by farmers. Wahi and Hakika varieties and Wahi and Sila varieties were second group in terms of generating positive net-returns when compared to other improved varieties the ox-plough/manure and JEMBE/manure technologies. Hakika and Pato varieties performed poorly and recorded negative net-returns for ox-plough and JEMBE without manure application. Though relatively low compared to other varieties, net-returns from Sila, Wahi, and Tegemeo were consistently positive and increasing. Local varieties recorded positive returns with ox-plough with manure applications and other management practices minimized loses when compared to the reference farm management practice (JEMBE without manure application).

The estimated average marginal returns for improved varieties under JEMBE without manure application was 7.32 percent and for ox-plough without manure application, JEMBE with manure application, and ox-plough with manure application were 6.96, 4.64, and 5.21%, respectively (Table 4). The highest marginal returns as shown in Table 4 was moving from the

Table 4. Estimated total revenue, total cost, and net-returns (1000 Tshs/ha).

Technology	Seed type	Total revenue	Seed cost	Labor cost	Total cost	Net returns	Marginal returns (%)
Ox-plough/manure	Tegemeo	1,056	12	797	809	246	3.74
	Pato	1,317	11	838	849	468	4.48
	Macia	2,136	8	882	890	1,246	7.30
	Mtama-1	1,840	10	840	850	990	6.81
	Wahi	1,365	9	830	839	525	4.84
	Hakika	1,366	9	830	839	527	4.84
	Sila	1,273	15	820	835	438	4.46
	Local	961	10	695	704	256	4.93
JEMBE/manure	Tegemeo	1,099	12	774	787	313	4.26
	Pato	1,165	11	816	827	339	4.06
	Macia	1,426	8	861	870	557	4.69
	Mtama-1	1,613	10	815	826	787	6.22
	Wahi	1,261	9	808	817	444	4.66
	Hakika	1,134	9	807	816	318	4.04
	Sila	1,221	15	797	812	409	4.53
	Local	642	10	668	678	-35	2.84
Ox-plough	Tegemeo	714	12	547	560	154	10.32
	Pato	668	11	588	598	70	5.58
	Macia	892	8	632	640	252	6.42
	Mtama-1	941	10	589	599	343	9.85
	Wahi	680	9	581	590	90	6.29
	Hakika	575	9	580	589	-13	4.51
	Sila	632	15	570	585	47	5.77
	Local	400	10	514	523	-123	5.52
JEMBE	Tegemeo	627	12	525	537	90	13.05
	Pato	525	11	564	575	-50	4.31
	Macia	701	8	609	617	84	5.12
	Mtama-1	735	10	566	576	159	8.58
	Wahi	618	9	556	565	53	7.21
	Hakika	572	9	556	565	7	6.10
	Sila	588	15	546	561	27	6.91
	Local	319	10	490	500	-181	

All results are through simulation using Equation 2. The estimates are therefore from respective expected values and not arithmetic means (that is, in Equation 2 $E(x) = \sum xf(x)$).

reference management practice to adoption of Tegemeo variety (13.05%) that increased revenue from 319,000 Tshs/ha to 627,000 Tshs/ha (a 96.6% increase) and increased total cost from 500 Tshs/ha to 537 Tshs/ha (a 7.4% increase). Results in Table 4 also showed that ox-ploughing Tegemeo variety field generated the second highest marginal returns (10.32%). Other varieties that recorded substantial high marginal returns were Mtam1 for ox-plough without manure applications (9.85%), Mtama-1 (8.58%), and Wahi (7.21%) varieties under JEMBE without manure application and Macia (7.3%) under ox-plough with manure application. The lowest gains were Tegemeo (3.74%) under ox-plough and manure applications, and Hakika (4.04%) and Pato varieties (4.06%) under JEMBE manure farm management practices. These results imply that for poor farmers facing both limited resources and incremental cost constraint, adoption of Mtama-1 and Tegemeo is highly recommended. Farmers who are not facing incremental cost constraints, Mtama-1, Macia, and Wahi varieties are the best-bet varieties for adoption when compared to other improved varieties.

Table 5. Mean yield and variance comparison across farm management practices.

Variety	Mean yield	Standard error	Mean yield	Standard error	P-value equal mean	P-value equal variance
	Ox-plough/Manure		JEMBE/Manure		Significance test	
Tegemeo	1882.66	5.74	1958.78	4.99	2.69E-6***	0.0006***
Pato	2786.82	6.27	2458.08	6.70	0.03485**	0.1856
Macia	3796.19	7.96	2531.58	7.69	0.2629	0.2385
Mtama-1	2823.50	8.38	2480.75	6.61	0.0005***	0.0004***
Wahi	2612.55	6.28	2407.36	7.05	0.0006***	0.0003***
Hakika	2604.89	9.10	2161.68	8.68	0.1277	0.0717*
Sila	2388.96	4.57	2297.25	6.71	0.0002***	0.0006***
Landrace	1565.71	2.30	1048.17	2.01	0.0005***	0.0004***
	Ox-plough		JEMBE		Significance test	
Tegemeo	1266.58	9.74	1114.29	10.31	0.0446**	0.1014
Pato	1414.02	10.24	1111.13	10.96	0.1320	0.2087
Macia	1587.38	14.06	1246.08	14.07	0.8783	0.5931
Mtama-1	1440.99	15.58	1129.56	10.67	0.0006***	0.0002***
Wahi	1312.22	11.57	1190.31	13.94	0.0009***	0.0007***
Hakika	1092.43	15.92	1091.32	13.84	0.0006***	0.0005***
Sila	1180.04	9.30	1113.05	11.24	0.0009***	0.0007***
Landrace	654.10	4.20	520.12	3.48	0.0008***	0.0005***

Three, two, and one asterisk (s) implies significant at 1, 5, and 10% level of significance.

Distribution of yield and net-returns

The mean and variance tests on yield distribution by land cultivation methods and management practices are presented in Table 5 and graphically in Appendix 1. The ox-plough and manure application farm management practices were compared to JEMBE with manure application. Also, ox-plough without manure application was compared to JEMBE without manure application. In Table 5, the hypotheses are that mean yield of varieties from ox-plough with manure application is equal mean yield from JEMBE with manure applications or mean yield from ox-plough without manure application and mean yield from JEMBE without manure applications are equal. The probability values were estimated using the Welch's and Levene’s t-test for respectively, the means and variances equality test. In Table 5, the means and variances that are statistically significantly different are denoted with asterisks. Statistical significance means that the null hypothesis stating that the compared means or the compared variances are the same is rejected. This means that there is significant statistical evidence to suggest that the means yield and the variances are different across respective farm management practices. For example, the means and variance for Tegemeo variety under ox-plough with manure application and ox-plough without manure application are statistically significant different. Farmers who grow Tegemeo in field cultivated by JEMBE and applying manure are more likely to get high yield and low yield variability compared to farmers who plant the same variety in ox-ploughed filed and apply manure. Standard error is the standard deviation divided by the square root of number of observations; an estimate of the standard deviation of the sample mean based on population mean. Since the standard deviation indicates the risk by showing just how the yield is spread, low value of standard error is preferred to larger value of standard errors.

Comparing ox-plough with manure application and JEMBE with manure application Pato variety had high yield under the former management practices but the spread or the yield distribution was similar across the two practices. The mean and distribution were similar for Macia variety. The varieties that shown statistically significant mean yield and differences in distribution across the two management practices were Mtama-1, Wahi, Sila, and landrace. All varieties indicated high yield under ox-plough with manure application. In both practices the landrace had the lowest standard error. Other varieties with lower standard error were Sila and Wahi varieties and ox-plough and manure application and Mtama-1 and Sila varieties with JEMBE but without manure application. For the two management practices Macia, Mtama1, and Hakika varieties are suitable for risk takers who focus only on yield outcome. Pato, Wahi, Sila, and Tegemeo varieties are for farmers who are relatively risk-averse and consider both yield and yield variability in the adoption process.

Comparative analysis results for mean yield and distribution from ox-plough without manure applications

Table 6. Mean net-returns comparison across different farm management practice.

Variety	Mean net return	Standard error	Mean net return	Standard Error	P-value equal mean	P-value equal variance
	Ox-plough/Manure		JEMBE/Manure		Significance test	
Tegemeo	246,398	3,645	312,716	3,270	0.0028**	0.0125*
Pato	468,467	4,120	338,931	3,977	0.4122	0.5349
Macia	1,245,839	5,685	556,827	4,866	0.0007***	0.0008***
Mtama-1	989,941	6,613	786,917	5,266	0.0005***	0.0004***
Wahi	525,279	6,195	444,020	6,231	0.6868	0.9320
Hakika	526,520	7,457	317,727	6,737	0.0002***	0.0012**
Sila	438,124	5,505	409,058	6,064	0.0012**	0.0030**
Landrace	256,371	3,717	-35,392	3,324	0.0002***	0.0001***
	Ox-plough		JEMBE		Significance test	
Tegemeo	154,008	5,521	89,742	5,943	0.0417*	0.1090
Pato	69,706	5,090	-49,643	5,318	0.1099	0.1136
Macia	251,865	8,109	84,193	8,039	0.8130	0.8658
Mtama-1	342,520	10,329	158,918	7,168	0.0005***	0.0009***
Wahi	90,100	6,558	53,119	7,581	0.0003***	0.0005***
Hakika	-13,246	8,761	6,631	7,629	0.0006***	0.0003***
Sila	46,868	5,646	27,119	6,394	0.0002***	0.0002***
Landrace	-123,221	2,832	-181,272	2,381	0.0008***	0.0007***

Three, two, and one asterisk (s) implies significant at 1, 5, and 10% level of significance respectively, using Welch-test for equal means and Levene-test for equal variances.

and JEMBE without manure application indicates that Mtama-1, Wahi, Hakika, Sila, and Landrace varieties were statistically significant different (have different mean yield and distribution). For this group of varieties, yield was relatively high and Mtama-1 and Wahi have relatively high mean yield under the two practices. The mean and yield distribution of Pato and Macia were relatively similar in both practices. The mean yield for Tegemeo under ox-ploughing was relatively high when compared to mean yield under JEMBE without Manure application. From these results, it can be concluded that manure application as a soil amendment tools highly increased marginal yield. However, the tradeoff between ox-ploughing and using JEMBE for land cultivation is less obvious.

Table 6 shows results on mean net-returns comparison across the four management and the interpretation is analogous to the result presented in Table 5. Varieties with similar net-returns distribution under ox-plough with manure application and JEMBE with manure application were Pato and Wahi varieties. For other varieties, the distributions were different (that is, mean and variance of net-returns were different). Under ox-plough and JEMBE without manure application, Pato and Macia varieties had similar distribution. Tegemeo variety has similar mean but different spread. Other varieties had similar distribution across the two farm management practices. Notice that the net-returns from Landrace under ox-plough with manure application may be superior to farmers with objectives of minimizing yield spread when compared to adopting improved seeds and ox-ploughing without manure application.

Stochastic dominance analyses

The CDFs from stochastic dominance analysis in Figures 1 and 2 were formed from the probability distribution of yield and net-returns of the different varieties under each farm management practice. Results for yield in Figure 1 indicate that under ox-plough and manure application, Macia variety is second-degree stochastic dominant to other varieties since its CDF lies below and to the right of other varieties. It is obvious in Figure 1 that all improved varieties dominate the landraces or local varieties. Tegemeo variety followed by Sila variety are also dominated by other improved varieties. Mtama-1 and Pato varieties dominate Hakika and Wahi varieties.

Results in Figure 1 also show that Pato variety dominated Mtama-1 variety at lower yield level and crosses Mtama-1's CDF at a cumulative probability of about 0.3. This indicates that Pato variety has highest yield about 30% of the time compared to Mtama-1. Since low yield is associated with adverse weather events, Risk-averse farmers would prefer Pato to Mtama-1 and risk neutral farmers would prefer Mtama-1 to Pato variety. In addition, Wahi variety dominated Hakika at lower yield level and crosses Hakika's CDF at a cumulative probability of 0.5. The results imply risk-averse decision-

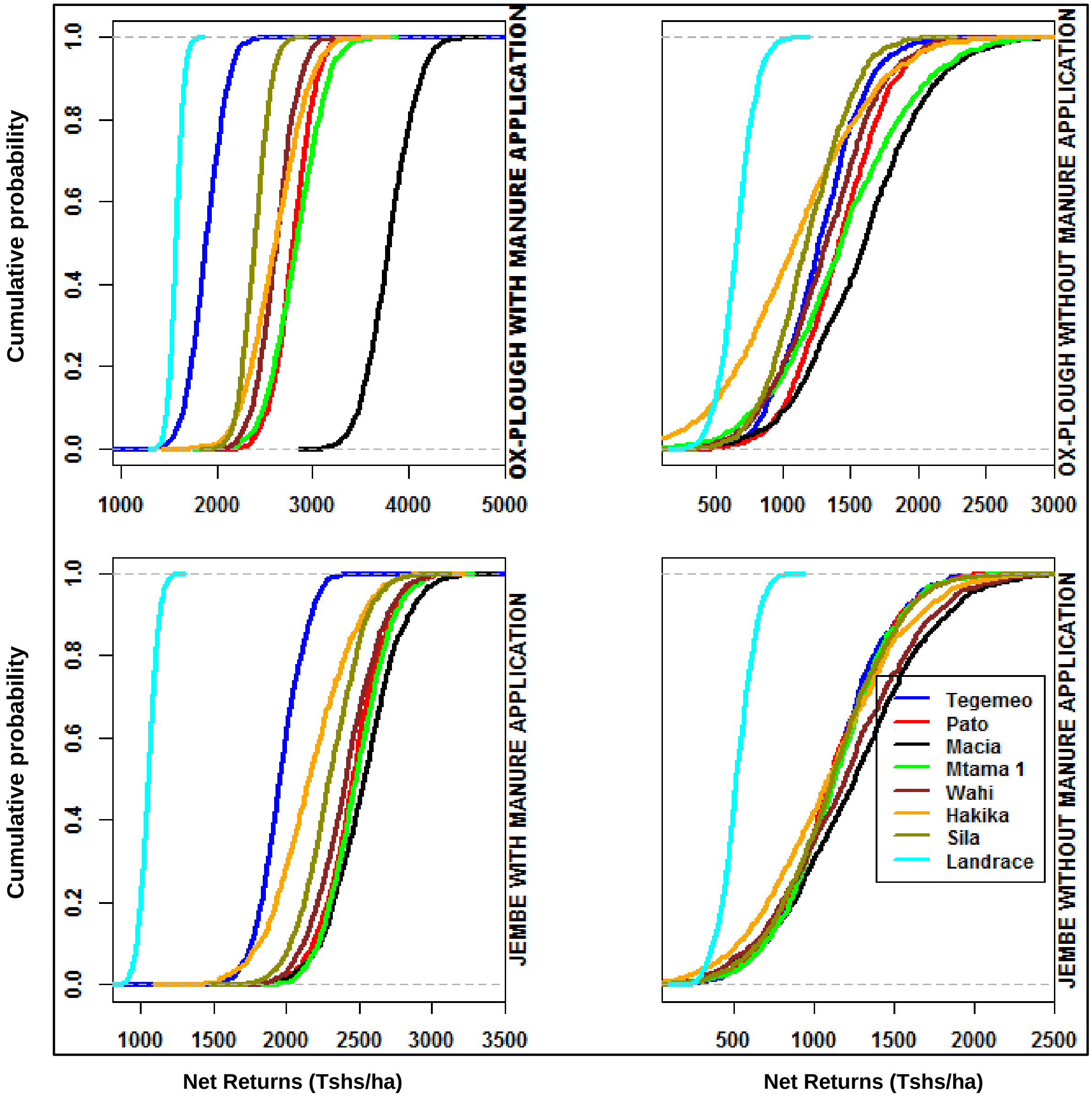

Figure 1. Cumulative distribution of yield in kg/ha.

makers will be incapable of discerning a preferred dominant variety between Wahi and Hakika varieties.

Figure 1 also show that for other farm-management practices, Macia variety is still second-degree stochastic dominant compared to other varieties. All improved varieties also dominate the landrace varieties. Results for JEMBE with manure application are almost similar to the results of ox-plough with manure application discussed above. Also in Figure 1, results for ox-plough without manure application are almost similar to results for JEMBE without manure application. While Pato and Mtama-1 relatively dominates the other four improved varieties, the CDF of Pato variety lie below and to the right of Mtama-1 until a cumulative probability of 0.5 is reached, where it crosses the CDF of Mtama-1. For the other four varieties, Figure 1 revealed that the CDFs crosses at several points. The CDF of Tegemeo crosses (from below) the CDFs of Mtama-1, Pato, and Hakika varieties at a cumulative probability of 0.1, 0.2, and 0.8, respectively. Also, the CDF of Sila variety crosses (from below) the CDFs of Mtama-1 and Hakika varieties at a cumulative probability of 0.1 and 0.7, respectively. Risk averse farmers will prefer Tegemeo and Sila varieties and risk neutral farmers would prefer Pato and Hakika under ox-plough and JEMBE without manure application.

The CDFs of net-returns in Figure 2 reveal that Macia and Mtama varieties alternatively dominated all other varieties under ox-plough and JEMBE with manure

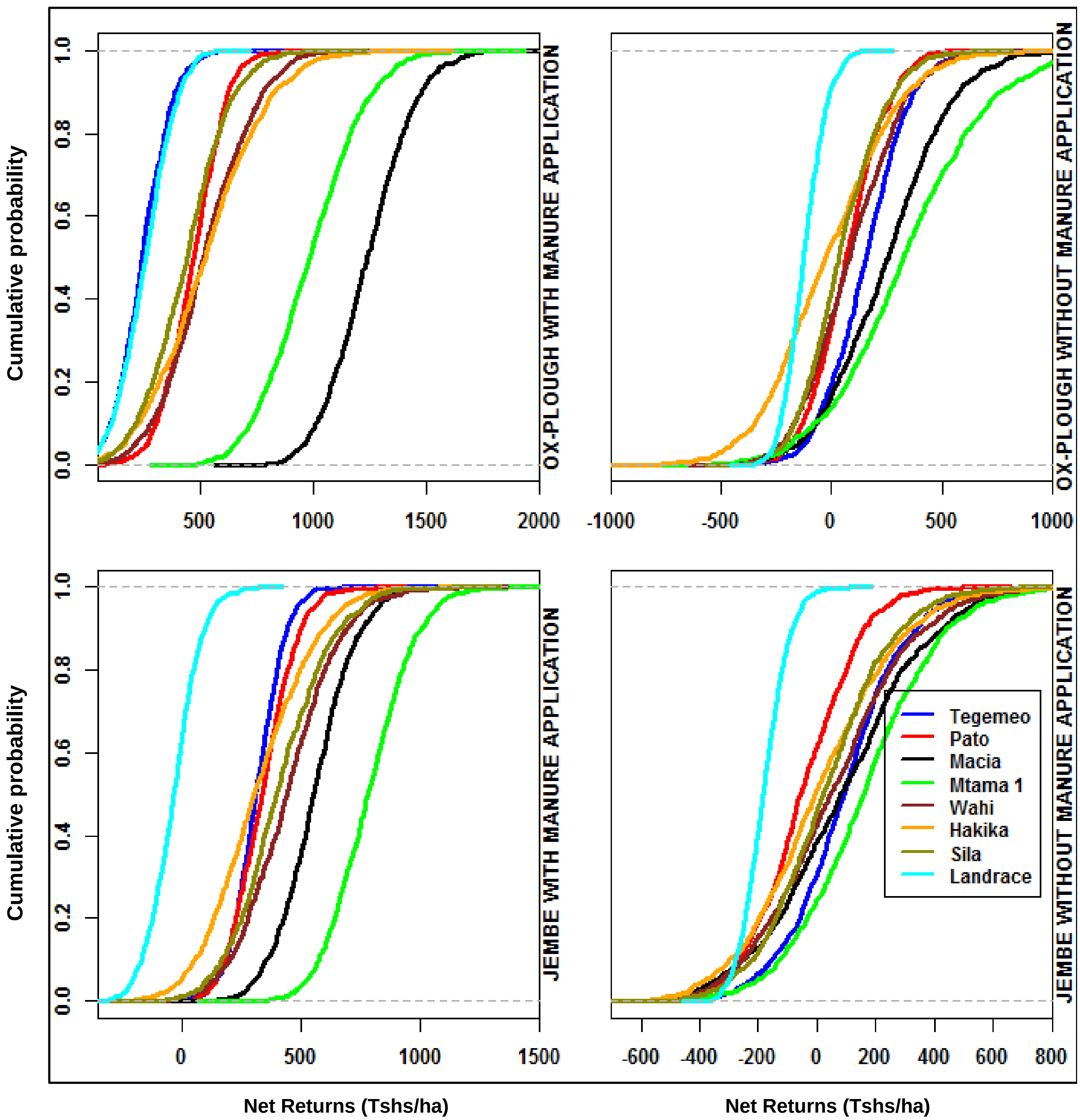

Figure 2. Cumulative distribution of net returns in 1000 Tshs/ha.

application and Wahi variety dominate other varieties under JEMBE with manure application. All varieties dominated Tegemeo and landrace varieties under ox-plough with manure application. All varieties also dominated landraces under JEMBE with manure application. Results in Figure 2 also show multiple lower-tail crosses among different improved sorghum varieties under ox-plough without manure application and JEMBE with and without manure application. For example, the Hakika variety under ox-plough without manure application dominates the landrace varieties when the net loss is about 100 Tshs/ha (at about 30% of the time). The CDF for Sila variety lies below and to the right and crosses the CDF for Hakika variety when net-returns equal zero (at a breakeven point) and when the cumulative probability is about 0.7. Therefore, net-returns for Hakika variety are negative 70% of the times compared to Sila variety. Under similar farm management practice, the CDFs for Pato and Tegemeo lies below and crosses the CDFs for Wahi, Macia and Mtama -1 when the cumulative probability are respectively 0.3, 0.1 and 0.05 and when net-returns is zero.

Under JEMBE with manure applications, the four varieties with multiple crossing are Tegemeo, Pato, Hakika, and Sila. Among the four varieties, Sila is the variety with the highest net returns above a net returns level of 250,000 Tshs/ha (at about the 70% of the time). The CDF for Pato variety lies below and to the right and crosses the CDF for Hakika variety when net-returns equal about 400,000 Tshs/ha when the cumulative probability is about 0.65.maize. Risk averse farmers would relatively prefer Pato to Sila and risk takers would prefer Sila to Pato. Similarly, the CDF for Tegemeo variety lies below and to the right and crosses the CDF for Hakika variety when net-returns is about 200,000 Tshs/ha and when the cumulative probability is about 0.5. Therefore, risk adverse farmer would be indifferent between Tegemeo and Hakika variety under JEMBE with manure application. Under JEMBE without manure application, there are several multiple crosses before the breakeven point when the net-returns equal to zero and the cumulative probability is less than 0.2. Under this scenario, Mtama-1 and Tegemeo minimize losses followed by Sila, Macia, and Pato varieties. When net-returns are positive (80% of the time), Mtama-1 dominate all other varieties and landrace and Pato varieties are dominated by all other varieties. The CDF for Tegemeo variety lies below and to the right and crosses the CDFs for Macia and Wahi varieties when net-returns equal about 100,000 Tshs/ha and 200,000 Tshs/ha and with the cumulative probability of about 0.5 and 0.75, respectively. Again, farmers who are risk averse would be indifferent between Tegemeo and Macia varieties and farmers who are risk averse would prefer Tegemeo to Wahi variety.

Stochastic efficiency with respect to a function (SERF) provides a more restrictive approach than stochastic dominance. To avoid dividing by zero the range of ARAC needed for the analysis was calculated by dividing the relative risk-aversion coefficients of between 0.00001 and 4.00 by the expected yield or net-returns of the reference technology. The estimated expected yield using Equation (3) were 1,561.96, 1,046.26, 652.45 and 518.25 kg/ha under ox-plough with manure application, ox-plough without manure application, JEMBE with manure application, and JEMBE without manure application. The respective expected net-returns were 255,499.40 Tshs/ha, -34,400.59 Tshs/ha, -122,226.00 Tshs/ha, and -1779, 678.80 Tshs/ha under similar farm management practices. The respective certainty equivalent for each ARAC, which was estimated using Equation 1 are presented in Figure 3.

The results of SERF for yield in Figure 3 show that the CEs relative to ARAC curve for all varieties decrease as the farmers become more risk averse and the net-returns necessary to make the decision-maker indifferent between alternatives decreases. The results also show that Macia variety was a superior choice under ox-plough with manure application since it has higher certainty equivalents across the range of expected producer risk preferences of 0.00 to 0.003. The second-most preferred choices are Mtama-1 for risk neutral farmer and farmers who are moderately risker. For extreme risk-averse farmers, they will be indifferent to growing Mtama-1 or Pato varieties. Moreover, indifference may also occur between Wahi and Pato varieties for relatively risk neural farmers whereas for risk averse farmers Wahi is superior to Pato variety. There are clear boundaries between different varieties under JEMBE with manure application and Macia variety was the superior choice followed by Mtama-1 and Pato. Tegemeo was an inferior choice. Under ox-plough and JEMBE with manure application Hakika variety was an inferior choice and superiority of other varieties depend on risk preferences. For relatively risk neutral and moderately risk averse farmers, superior choices (ranked in term of relative importance under ox-plough without manure application) are Macia, Pato, Mtama-1, Wahi, Tegemeo, and Sila. For extremely averse-farmers, superior varieties under similar management practices are Pato, Macia, Tegemeo, Wahi, Sila, and Mtama-1.

Comparable SERF results for net-returns under different management practices are shown in Figure 4. Macia and Mtama-1 varieties under ox-plough with manure application present a clear superiority choices and Tegemeo is an inferior choice when compared to other varieties. For moderately risk averse farmers, superior choices would be Wahi, Sila, Pato, and Hakika; and for risk averse farmers, the choices would be Pato, Wahi, Sila, and Hakika. Except for highly extreme risk averse farmers a list of superior choices under ox-plough without manure application are Pato, Macia, Tegemeo, Wahi, Sila, and Mtama-1. Expect for Macia and Wahi varieties that crosses for extremely risk-averse farmers, the order of reducing production and price risk under JEMBE with manure application are respectively, Mtama-1, Wahi, Macia, Sila, and Hakika and inferior choices are Tegemeo and Pato. Equivalently, for risk neutral and moderately risk averse farmers, a list of superior choices under JEMBE without manure application include Wahi, Mtama-1, Hakika and Macia and inferior choices are Pato, Sila, and Tegemeo. For extremely risk averse-farmers, the respective similar list is Mtama-1, Macia, Wahi and Tegemeo varieties as superior choices and Pato, Sila, and Hakika varieties as inferior choices.

A utility-weighted risk premium is calculated as the difference between the CE values using a dominant variety in each farm management practice. A risk premium is defined as the additional yield or net returns

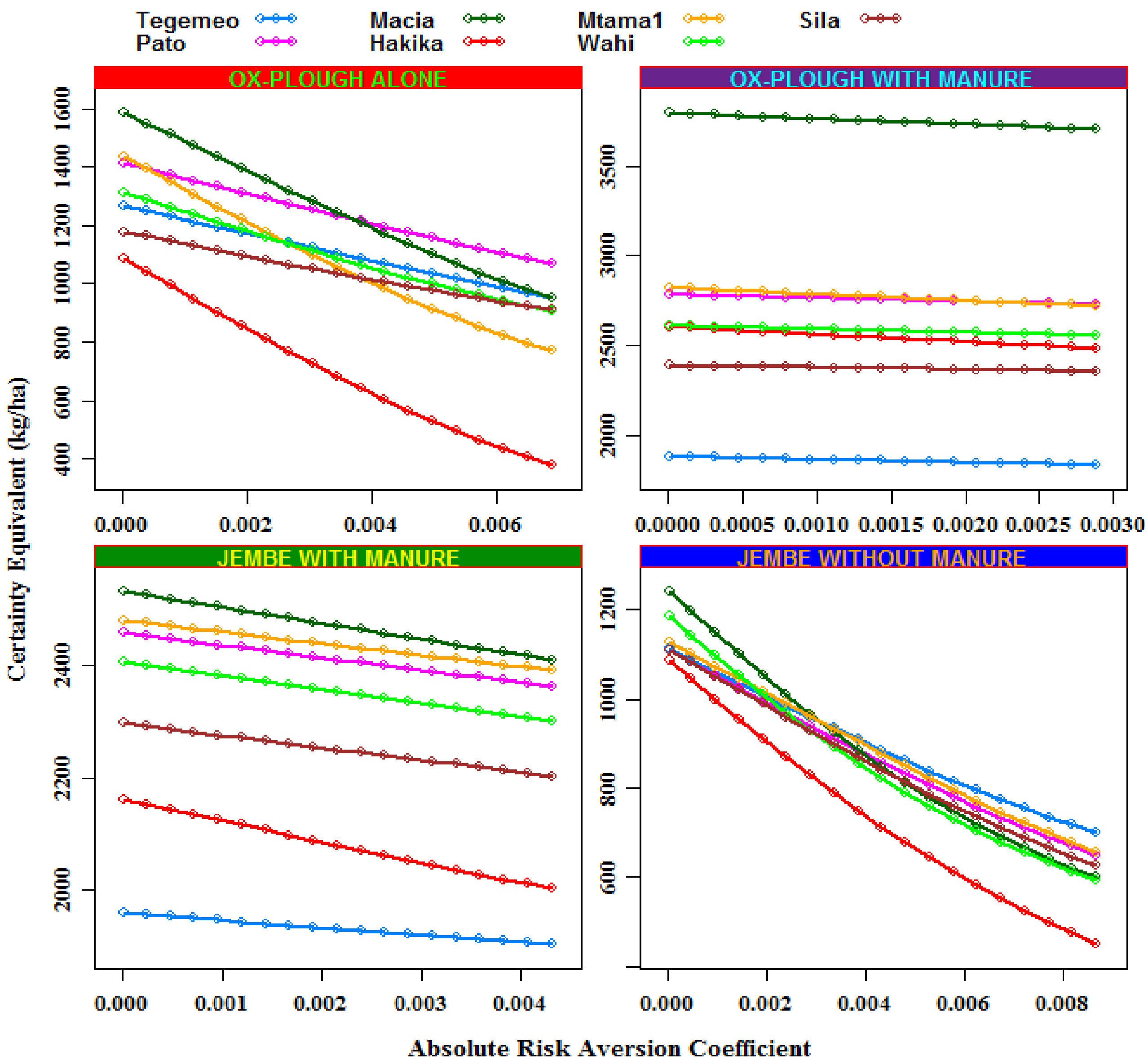

Figure 3. The SERF results for yield.

that farmers would have to be compensated to convince them to switch to an alternative sorghum variety. To estimate average premium for each variety under each management practice, we used the Z-value of $r_a(x)$ (standardized $r_a(x)$) to categorize group risk into four groups: Risk neutral; moderately risk averse; very risk averse; and, extremely risk averse. The category is Risk neutral if the Z-value were less than -1; moderately risk averse if the Z-value are between -1 and 0; very risk averse if the Z-value are between 0 and 1; and extremely risk averse if the Z-value are greater than one.

Results of estimated average risk premium are presented in Table 7. Reading the Table (row wise), the zero values in the table represent a variety with low risk or a variety with the highest certainty equivalent. Macia is a row risk variety for JEMBE with manure application, Tegemeo is a low risk variety for JEMBE without manure application but only for risk neutral and moderately risk averse farmers. Since a risk premium is the actual excess of the expected return on a risky asset over the known return on the risk-free asset, higher values of risk premium in Table 7 imply that farmers must be paid much higher compensation to convince them to switch from variety with lower risk to another variety with relatively higher risk and vice versa. Generally, farmers who are risk neutral are willing to forego (less amount of returns) to switch from low risk variety to a relatively high risky variety.

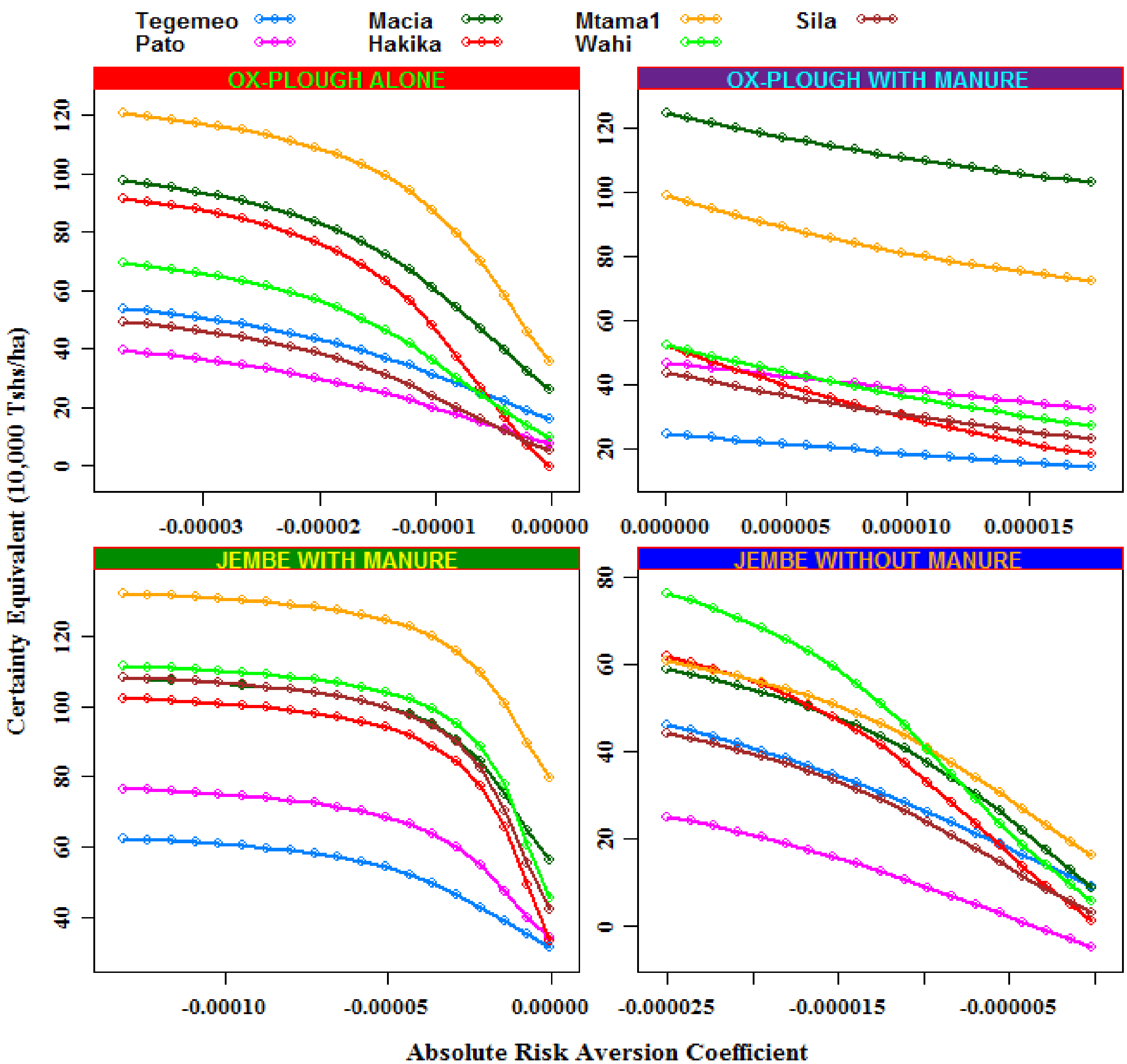

Figure 4. The SERF results for net returns (1000 Tshs/ha).

Results in Table 7 show that extremely risk averse farmers who produce Macia variety under JEMBE with manure application, would have to be compensated with 567 kg/ha or 71 kg/ha to switch to Tegemeo and Pato varieties, respectively. Macia producers that are risk neutral, would require compensation of about 510 and $49 kg/ha to switch to Tegemeo and Pato varieties, respectively. For the yield subsection, high risk premium is recorded in the ox-plough with manure application farm management practice. For example, risk-neutral producers must be paid almost 1,877 kg/ha to switch from Macia to Tegemeo variety, and extremely risk-averse producers must be paid $1,910 kg/ha to switch to Tegemeo variety.

Generally, high compensations were needed under ox-plough with manure application and JEMBE with manure application to respectively switching from Macia varieties to all other varieties and from Macia to Tegemeo varieties. Low compensations were needed under JEMBE with manure application and JEMBE without manure application to switching from Macia varieties to Mtama-1 and Pato varieties and from Macia to Pato varieties, respectively. However, due to relatively higher price, in terms of net-returns; Mtama-1 is the preferred variety for producers under JEMBE with manure, ox-plough alone, JEMBE without manure application for moderately risk averse and very risk averse farmers. Also, in terms of net-returns, Macia is the first choice for

Table 7. Estimated mean risk premium for yield and net-returns.

Group	Risk category	Tege-meo	Pato	Macia	Hakika	Mtama1	Wahi	Sila
Mean risk premium for yield (kg/ha)								
JEMBE with manure	Risk Neutral	510	49	0	404	21	109	209
	Moderately risk averse	527	55	0	395	29	113	215
	Very risk averse	548	64	0	384	39	118	224
	Extremely risk averse	567	71	0	373	48	123	232
\JEMBE without manure	Risk Neutral	0	46	94	239	37	103	69
	Moderately risk averse	0	25	57	194	10	74	45
	Very risk averse	82	21	0	138	67	34	32
	Extremely risk averse	97	105	0	150	85	52	106
Ox-plough alone	Risk Neutral	119	0	103	675	285	164	166
	Moderately risk averse	126	0	23	589	210	152	190
	Very risk averse	209	75	0	542	178	203	286
	Extremely risk averse	300	155	0	505	154	262	385
Ox-plough with manure	Risk Neutral	1,877	981	0	1,219	985	1,154	1,354
	Moderately risk averse	1,887	989	0	1,212	982	1,162	1,369
	Very risk averse	1,899	998	0	1,202	977	1,172	1,386
	Extremely risk averse	1,910	1,007	0	1,194	974	1,181	1,402
Mean risk premium for net-returns (1 000 Tshs/ha)								
JEMBE with manure	Risk Neutral	577	506	247	385	0	266	323
	Moderately risk averse	700	557	246	307	0	205	249
	Very risk averse	698	556	241	299	0	205	241
	Extremely risk averse	696	554	239	297	0	205	238
JEMBE without manure	Risk Neutral	87	234	61	143	0	95	143
	Moderately risk averse	148	318	42	92	0	21	175
	Very risk averse	259	451	125	120	99	0	271
	Extremely risk averse	296	502	165	139	144	0	312
Ox-plough alone	Risk Neutral	320	412	162	400	0	357	421
	Moderately risk averse	598	718	264	372	0	520	663
	Very risk averse	663	799	247	310	0	519	706
	Extremely risk averse	688	809	234	292	0	512	711
Ox-plough with manure	Risk Neutral	893	710	0	843	305	755	800
	Moderately risk averse	912	717	0	821	300	747	802
	Very risk averse	945	737	0	782	285	736	803
	Extremely risk averse	985	766	0	736	264	724	806

farmers under ox-plough with manure application and Wahi is the first choice for farmer who uses JEMBE for land cultivation and are very or extremely risk averse.

Conclusion

In this study, we use farm survey data to estimate yield and net-returns from landraces or local and improved sorghum varieties in Tanzania. The data were collected from 822 sample households in major sorghum farming systems in Central, Western, and Northern Tanzania. About 505 sample households were adopters (61%) and 317 nonadopters (39%) of improved sorghum varieties. Extension officers working in the region were trained and were instrumental in pretesting the questionnaire and in data collection. During the survey, respondents were knowledgeable farmer at the household level. We used different approach including simulation, bootstrapping, stochastic dominance analysis, and stochastic efficiency with respect to a function to examine yield and risk associated with adopting improved sorghum varieties by small-scale farmers. In the farming system, ox-plough and JEMBE (handhole) were the main implements for land cultivations, manure application was the main soil amendment practice, and the farmers either planted improved or landraces/local varieties or both as a monocrop.

The results show that small-scales planting landraces typically face negative net-returns when all costs of production are considered. Results from stochastic dominance analysis and stochastic efficiency with respect to a function reveals that manure application and ox-ploughing are important farm practices with a potential of shifting the production function by increasing both yield and reducing yield variability. Macia and Mtama-1 were second-degree stochastically dominant to all other varieties under ox-ploughing and JEMBE with manure applications. In terms of yield; results from stochastic efficiency with respect to a function indicate that Macia is the preferred variety for producers over the entire range of risk preferences under JEMBE and ox-plough with manure application. The variety was also preferred for extremely risk averse-farmers under ox-plough and JEMBE without manure application.

Pato variety was preferred by risk neutral and moderately risk averse farmers under ox-plough without manure application. In term of net-returns, Mtama-1 and Macia varieties were predominantly first choice varieties. The two varieties dominated other varieties due to high yield and price. High price is attributed to market opportunities opened by the growing demand from the brewery and animal feed industries. These new opportunities are allowing farmers to receive significantly high price and invest more in production activities such as ploughing and manure application. Although these activities add cost, the marginal gain in yield and net-returns are enough to outweigh marginal costs. There is therefore a need to simultaneously promote the adoption of improved sorghum varieties in the area and develop new market opportunities and value adding activities along the value chain. Since most farmers are using manure as a soil amendment activity, there is a need of conducting studies to establish manure application rate and developing improved varieties that are more responsive to manure application. Also, promoting small-scale mechanization (use of ox-plough) will increase both production and productivity of available limited resources in the region.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Commodity prices, exchange rate and economic growth in West Africa: Case study of Cote d'Ivoire and Ghana

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Some West African countries have extensive access to natural resources and rely heavily on revenues from the export of these primary commodities. The heavy dependence of Ghana and Cote d'Ivoire on revenues from the exportation of cocoa raises the possibility that these economies are vulnerable to external commodity price fluctuations. This paper seeks to examine the relationship between cocoa prices, exchange rate and economic growth using time series data for the period 1980 to 2011. Using autoregressive distributed lag (ARDL) modelling approach, the study found intriguing results. The study revealed that higher cocoa price reduces long-run economic growth in Ghana but cannot be an important ingredient in short-run growth. In Cote d'Ivoire, it does not play any significant role in both long-run and short-run economic growth. Increases in cocoa exports rather enhance economic growth of the two countries. Appreciation of the Communaute Financiere Africaine (CFA) franc enhances economic growth but that of the Ghana Cedi is only in the short-run. Higher rates of inflation reduce economic growth of Ghana but enhance that of Cote d'Ivoire. Improvements in life expectancy augment economic growth in Ghana but reduce that of Cote d'Ivoire.

Key words: Cocoa price, cocoa export, inflation, exchange rate, economic growth.

INTRODUCTION

In recent times, exchange rate movements have been unusually large and this has triggered debates on their likely effects on trade and economic growth of commodity exporting countries. For instance, the U.S. dollar has appreciated by more than 10% in real effective terms since mid-2014. The euro has depreciated by more than 10% since early 2014 and the yen by more than 30% since mid-2012. Such movements, although not unprecedented, are well outside these currencies' normal fluctuation ranges. Even for emerging markets and developing economies, whose currencies typically fluctuate more than those of advanced economies, the recent movements have been unusually large. Krugman (2015) predicted strong impacts of these large exchange rate movements on trade, hence influencing economic activities.

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According to Issa et al. (2008), long-run economic growth of commodity-rich countries does not correlate with commodity prices but short-run economic growth does. One relevant question raised here is: What is the economic mechanism that drives the short-run movement between commodity prices and growth to varnish in the long-run? The neoclassical growth model is consistent with these two facts. Here, the long-run (steady-state) growth is determined by the pace of exogenous technical progress as such by construction independent of commodity prices. In addition, movements in commodity prices would affect short-run growth but only through transitional dynamics (Rebelo and King, 1993; Cogley and Nason, 1995).

There are different stories of how Ghana's "black gold" cocoa, was introduced to Ghana. It was an indigenous plant in the rain forests of Central and Southern America, and so rare and expensive that only the royalty of Inca or Aztecs were permitted to eat it. It was used to coat turkeys when they were roasted or baked. It was forbidden to cultivate the plant or export it. The Portuguese and Spanish both stole cocoa plants to grow elsewhere. When introduced to Europe, cocoa and the chocolate made from it, were very expensive, and a luxury only the wealthy could afford. The Swiss were interested in developing chocolate products as an expensive luxury food. The Swiss Missionaries who came to Gold Coast in the early nineteenth century wanted to convert the local people to cash cropping so as to monetize their economy. The Portuguese introduced it in Sao Palme also.

According to Ghanaian oral history, Tetteh Quarshie went to Fernando Po and stole some live beans to cultivate at Akropong Akwapem in Gold Coast**.** He sold the early harvest to local farmers and later in 1885 began exports to Europe. This spread to the neighbouring country, Cote d'Ivoire, which has the same vegetation as Ghana. In 1925, Ghana exported nearly 44% of the world's cocoa. In 1936 to 1937, British West Africa and French West Africa contributed 66% of total world exports in the following capacities; Ghana 42%, Nigeria 14%, Cote d'Ivoire 7%, and French Cameroons 3%. This rapid expansion of the cocoa industry made Ghana the most highly developed peasant export economy in Africa. This improved the developmental process of the country.

Economic growth of most developing countries is made up of exports. The exports of these countries especially in the Sub-Saharan African countries are commodities such as gold, metals, minerals, and agricultural products. Generally, commodity prices are popularly known for their volatility in world prices. These variations tend to induce a lot in the real national incomes hence a lot of challenges in the macroeconomic management of these countries.

Are continued fluctuations in commodity prices of developing countries affecting their economic growth? Or does the increases in these prices sow the seeds for the amelioration of inflation and exchange rate problem? These natural resources serve as inputs in the production of many goods and services.

Many studies have concentrated on variables that influence economic development of West African states but one issue that remains unclear, but important is the extent of the relationship between commodity prices, exchange rate variability and economic growth. This study looks at how the fluctuations in cocoa commodity price as a leading agricultural export influence the real growth in the GDP of Ghana and Cote d'Ivoire. The study intends to investigate if a boom in the price of cocoa on the world market contributes to high economic growth of Ghana and Cote d'Ivoire in order to promote a better understanding of the impact of commodity price movements on growth and the opportunities for economic growth that commodity production presents. It examines the effects of excessive commodity price volatility and exchange rate on economic growth. Ghana and Cote d'Ivoire are selected as they are the major cocoa producing countries in the world and relies heavily on revenues from the exports of this commodity. The dependence of Ghana and Cote d'Ivoire on revenues from the exports of cocoa highlights the vulnerability of these economies to external commodity price fluctuations.

LITERATURE REVIEW

Economists have used both theories and empirical studies to explain the causes of economic growth. Pritchett (2000) and Hausmann et al. (2005) explained that growth process in many developing countries lacks persistence. They argued that even many of the poorest countries have experienced temporary periods of rapid growth, but the difficulty is how to sustain it. Easterly et al. (1993) have shown that economic growth instability in developing economies might possibly be as a result of external shocks, particularly where instability in the terms of trade plays an important role. Elbadawi and Ndulu (1996) buttressed the proposition that external shocks have an indirect growth impact by inducing policy changes that often further contribute to poor growth performance.

Bjornland (2009) presented a transmission channel of how oil prices affect macroeconomic behaviour of oil exporting countries. The researcher postulated that the economy is affected by higher oil prices in two ways; first, higher oil prices signify an instantaneous transfer of wealth from oil importing countries to oil exporting countries, and lastly, through negative trade effects at higher oil prices, oil importing economies will demand less export of traditional goods and services from the oil exporting economies which may have an indirect influence on the oil exporting economies.

Commodity price volatility can influence long-term growth. This maybe so because strongly fluctuating prices increase uncertainty and risk which discourage the level of investment in the economy. Blattman et al. (2007) indicated that countries that specialize in commodities with substantial price volatility have more volatility in their terms of trade, enjoy less foreign direct investment, and experience lower growth rates than countries that specialize in commodities with more stable prices or countries that are industry leaders. Again, the researchers avowed that countries in the periphery with volatile commodity prices and undiversified economies fall behind in economic development.

Van der Ploeg and Poelhekke (2009) combined the natural resource literature with Ramey and Ramey (1995) to show that commodity price volatility drives the volatility of the share of natural resource exports in a country's GDP. The reason is that variability of the share of natural resources as part of GDP will, in turn, result in volatility of unanticipated output growth and depresses output per capita growth in countries that heavily depend on natural resources. Taken together, Van der Ploeg and Poelhekke (2009) showed that the share of natural resources in GDP has a positive effect on economic growth, while the volatility of this share has a negative growth effect.

Besides, the recent spikes in commodity prices have pushed up consumer prices in many countries, prompting calls for central banks to take pre-emptive action against an acceleration of inflation. Cecchetti and Moessner (2008) and Liu and Weidner (2011) stated that oil price shocks induce a rise in nominal wage rates. As such, high wage rates result in a further increase in consumer prices, as higher wage costs are passed on by employers to consumers. Krugman (2008) commented that the fear of inflation itself may possibly lead to policies that could worsen a bad economic situation.

As for the effect of oil prices on real exchange rate, Amano and Norden (1998), Huang and Guo (2007), Kutan and Wyzan (2005), Olomola and Adejumo (2006), Korhonen and Juurikkala (2009) and Narayan et al. (2008) have found that an increase in oil prices leads to an appreciation of the domestic currency. Policies adopted to counter inflationary pressure from rising commodity prices are also of crucial importance for the development of real exchange rates. To the extent that commodity price pressure translates into inflation, countries with a fixed nominal exchange rate will experience an appreciation of their real exchange rate with adverse consequences for the international competitiveness of their non-commodity sectors.

Trade activities involve a huge sum of funds invested by highly leveraged financial institutions like hedge funds and banks. Although their activities may not be directly related to trade, they have become the single most important determinant of cross-border capital flows. For instance, a large movement of flows into a target country leads to an appreciation of the respective country's currency and a depreciation of the currency of the funding country. This movement reinforces the flows as it increases the profit margin of the investor, who, in addition to interest rate differential, also expects a gain from the appreciation of the target currency. According to Aghion et al. (2009), real exchange rate volatility has a significant effect on the long-term rate of productivity growth, but the effect is subject to a country's level of financial development.

Chen and Rogoff (2003) analysed the relationship between commodity prices and exchange rates of three member economies of the Organistion for Economic and Co-operation and Development (OECD), namely Australia, Canada, and New Zealand. The authors found that commodity prices significantly drive the real exchange rates of Australia and New Zealand. The result was similar to the analysis of Cashin et al. (2004) who provided additional evidence for a larger set of developing-commodity exporting countries. Kutan and Wyzan (2005) incorporated oil price shocks into real exchange rate equation to determine the vulnerability of Kazakhstan to the Dutch disease. The findings revealed that changes in oil prices have a positive and significant effect on movements in the real exchange rate in Kazakhstan, as an increase in oil price results in an appreciation of the real exchange rate. Also, in Ghana, commodity prices such as cocoa and gold prices were found to be directly related to exchange rate. This is because Ghana is a net exporter of both cocoa and gold, and as a result when the prices of cocoa and gold increase, Ghana tends to reap greater revenues from its cocoa and gold exports. As the revenue from its cocoa and gold exportations increases, the value of the Ghanaian cedi improves, and hence the exchange rate appreciates as well (Buah, 2016).

Empirically analysing the relationship between the prices of minerals and the real value of the Rand of South Africa, Frankel (2007) reported that an index of mineral prices is one; which implies that mineral prices are important determinants of the real value of the Rand. This was particularly true in the times when the Rand was strongly appreciating in the real terms in-between the periods of 2003 and 2006. Mostly in developing countries, Ngandu (2005) validated the relationship between commodity prices and the real exchange rate of commodity exporting countries.

Rautava (2004) divulged that oil has played a significant role in movements of Russian GDP. Yet, the results obtained from the study indicated that a higher oil price does not lead to a stronger real exchange rate in Russia. In Norway, Bjornland (2004) alluded that an oil price shock stimulates the economy temporarily, however, it has no significant long-run impact. The study exhibited no evidence for the major part of real exchange rate appreciation in Norway being driven by oil price shocks.

Aghion and Banerjee (2005) explored the various causal linkages between economic growth and the volatility of commodity prices from empirical cross-country. It was found that commodity price volatility hurts economic growth. Evidence attained by Jimenez-Rodriguez and Sanchez (2005), Korhonen and Mehrotra (2009), and Bjornland (2009) indicated a positive impact of higher oil prices on the growth rate of Norway, Russia, Kazakhstan, Iran, and Venezuela. Meanwhile, oil exporting countries like the United Kingdom and Canada showed declining growth rates as a result of higher oil prices, hence behaving more like oil importing countries. Mostly, countries with larger oil sector compared to the economy have oil price changes affecting the economic cycle only through their impact on fiscal policy (Tazhibayeva et al., 2008).

Upreti (2015) shared the idea that a high quantity of exports, copious resources, longer life expectancy all have positive impacts on the growth rate of GDP in developing countries. However, the researcher proposed further studies to be conducted so as to characterise the causes of growth in less developed countries since he employed cross-country data for 76 less developed countries. Besides, Barro (1996) who realised that the real GDP per capita was associated with maintenance of the rule of law, small government consumption, longer life expectancy, higher levels of investment and a lower inflation rate used a panel of 100 countries from 1960 to 1990.

STUDY METHODOLOGY

Model specification

Economic growth is influenced by macroeconomic factors such as cocoa price, cocoa export, exchange rate, inflation rate, and life expectancy. Economic growth using a linear function is specified as follows:

$$lnGDPPC_t = \alpha_0 + \delta_1 lnCOP_t + \delta_2 lnCOEX_t + \delta_3 lnEXR_t + \delta_4 lnINFL_t + \delta_5 lnLE_t + \varepsilon_t \quad (1)$$

where GDPPC represents gross domestic product per capita (GDPPC) which is a proxy for economic growth, COP is the cocoa price, COEX represents the cocoa export, EXR indicates the exchange rate, INFL denotes inflation, LE represents life expectancy. α_0 and ε_t represent the constant and error term respectively. δ_i represents the elasticity of the respective variables and *ln* represents natural logarithm. The following are expected: $\delta_1 > 0, \delta_2 > 0,\ \delta_3 > or < 0, \delta_4 < 0, and\ \delta_5 > 0.$

Data source

The study used annual time series data covering the period 1980 to 2011 obtained from published sources. Data on cocoa prices and exports were extracted from Food and Agricultural Organisation's Statistics database. Data on gross domestic product per capita which is a proxy for economic growth, inflation rate, and exchange rate were retrieved from the World Development Indicators (2015).

Estimation strategies

ARDL cointegration test

Cointegration mechanism, according to Stock and Watson (1988) ensures that the information of non-stationary variables is captured without having to forfeit the statistical validity of the projected equation. To investigate the long-run relationship between cocoa price, exchange rate, economic growth and other controlled variables, this study did not pay attention to outdated cointegration techniques such as the two-steps Engle-Granger method and Johansen Maximum Likelihood Estimation. The study rather considered the newly advanced technique to test long-run relationship which may exist between the variables by using autoregressive distributed lag (ARDL) modelling technique developed by Pesaran and Shin (1998), and Pesaran et al. (2001) due to its several advantages relative to other single equation cointegration techniques. It is capable of computing the long-run and short-run parameters of the model concurrently in order to prevent the problems posed by time series data which are non-stationary. It does not require pre-testing of the order of integration among the concerned variables as compared to other techniques which dictate that the variables present the same order of integration. However, in this study, the Augmented Dickey-Fuller test for stationarity was used to ensure that none of the variables was integrated of order two [I(2)]. Again, the ARDL modelling technique is the more appropriate approach for examining the cointegration relationship in small samples.

Long-run and short-run relationships

A selected ARDL (m, n1, n2, n3, n4 and n5) model was employed to determine the long-term relationship of the variables. The long-term ARDL model equilibrium relationship was expressed as:

$$lnGDPPC_t = \gamma_0 + \sum_{i=1}^{m} \gamma_{1i} lnGDPPC_{t-i} + \sum_{j=1}^{n_1} \gamma_{2i} lnCOP_{t-j} + \sum_{k=1}^{n_2} \gamma_{3i} lnCOEX_{t-k} + \sum_{d=1}^{n_3} \gamma_{4i} lnINFL_{t-d} + \sum_{e=1}^{n_4} \gamma_{5i} lnEXR_{t-e} + \sum_{f=1}^{n_5} \gamma_{6i} lnLE_{t-f} + \varepsilon_t \quad (2)$$

In order to give more parsimonious model specification, the optimum lags were chosen based on the Schwarz Bayesian Criterion.

The error correction model captured the short run dynamics as follows:

$$\Delta lnGDPPC_t = \gamma_0 + \sum_{i=1}^{m} \gamma_{1i} \Delta lnGDPPC_{t-i} + \sum_{j=1}^{n_1} \gamma_{2i} \Delta lnCOP_{t-j} + \sum_{k=1}^{n_2} \gamma_{3i} \Delta lnCOEX_{t-k} + \sum_{d=1}^{n_3} \gamma_{4i} \Delta lnINFL_{t-d} + \sum_{e=1}^{n_4} \gamma_{5i} \Delta lnEXR_{t-e} + \sum_{f=1}^{n_5} \gamma_{6i} \Delta lnLE_{t-f} + \varphi ECM_{t-1} + \varepsilon_t \quad (3)$$

$where\ \gamma_i$ denotes the coefficient relative to short-run dynamics of the model's adjustment to equilibrium. ECM_{t-1} term is error correction factor and φ is interpreted as a speed of adjustment for the dependent variable to attain the equilibrium.

Diagnostic and stability tests were conducted to examine the goodness of fit of the ARDL model. Serial correlation, normality, functional form, and heteroscedasticity were used for the diagnostic tests, whereas cumulative sum of recursive residuals and cumulative sum of squares of recursive residuals were employed for the stability tests.

EMPIRICAL RESULTS AND ANALYSES

Descriptive statistics

Table 1 shows the descriptive statistics of the series. There are 32 observations representing the yearly time series data from 1980 to 2011. The standard deviation of the variables indicates variation or deviation of the series

Table 1. Descriptive statistics.

Study area	Variable	Observation	Mean	Std. Dev.	Min.	Max.
Ghana	lnGDPPC	32	6.556	0.187	6.264	7.024
	lnCOP	32	12.239	2.865	7.090	16.029
	lnCOEX	32	13.122	0.509	12.397	14.604
	lnINFL	32	3.152	0.674	2.166	4.811
	lnLE	32	4.040	0.041	3.957	4.108
	lnEXR	32	-2.582	2.696	-8.199	0.413
Cote d'Ivoire	lnGDPPC	32	12.830	0.330	12.330	13.325
	lnCOP	32	12.826	0.396	12.206	13.798
	lnCOEX	32	13.916	0.463	12.970	14.924
	lnINFL	32	1.264	0.878	-0.353	3.261
	lnLE	32	3.911	0.044	3.842	3.969
	lnEXR	32	6.062	0.335	5.353	6.597

from their mean values. All the series showed little deviation from the mean values. This is because the extent of deviation from the mean value is not substantial for gross domestic product per capita, cocoa price, cocoa export, inflation, life expectancy, and exchange rate for Cote d'Ivoire. However, in the case of Ghana, only the standard deviations of cocoa price and exchange rate were substantial. Gross domestic product per capita averaged around 6.56% over the 1980 to 2011 period, while the cocoa price also averaged around 12.24% over the same period. The exchange rate recorded an average of -2.58% over the 1980 to 2011, period while the cocoa export averaged 0.89% over the same period. Moreover, the gross domestic product per capita indicated a maximum rate of 7.02% and a minimum of 6.26%. The minimum level of cocoa price over the study period was 7.09%, whilst the maximum was 16.03%. Additionally, the exchange rate showed a minimum of -8.20% over the period with a maximum of 0.41%. The cocoa export recorded a minimum of 12.40% and a maximum of 14.60% for Ghana. Similar analyses were conducted for all the series considered in the study for Cote d'Ivoire.

Stationarity test

The Augmented Dickey-Fuller test was deployed to examine the level of stationarity of the variables used in the study. The results are shown in Table 2.

From Table 2, the results indicated that inflation and life expectancy were stationary at their levels after the use of the Augmented Dickey-Fuller (ADF) test for both countries (Ghana and Cote d'Ivoire). Also, the results indicated that gross domestic product per capita (proxied for economic growth), cocoa price, cocoa export, and exchange rate became stationary at their first difference using the Augmented Dickey-Fuller test in the case of Ghana and Cote d'Ivoire respectively.

Cointegration test

In analysing the long-run relationship among the variables, the study deployed ARDL Bounds Test approach to cointegration. Table 3 presents the results of the cointegration test.

The study considered the lower and upper bounds of the bounds tests at 1 and 5% levels of statistical significance. The F-statistics of 10.77828 and 12.95791 from both models were found to be greater than their respective upper boundary at a 1% level of significance. Hence, there exists a long run relationship amongst the variables for both countries. There would have been no cointegration should the F-statistic fall below the lower boundary and undetermined should it have fallen in between the upper and lower boundaries.

Long-run relationship

The results for the long-run relationship are captured in Table 4. Focusing on the results, it was found that cocoa price has an inverse relationship with economic growth in the long run with an explanatory power of -0.011690 which alludes that a 1% rise in the cocoa price reduces economic growth by 0.01% in Ghana. In the situation of Cote d'Ivoire, though it was insignificant, an increase in the price of cocoa helped improve the growth rate of the economy in the long run.

Cocoa export was significant and positively related to economic growth for the two major cocoa exporting countries (Ghana and Cote d'Ivoire). This implies that a 1% increase in the value of cocoa export will enhance economic growth by increasing it by 0.08% and 0.16% for Ghana and Cote d'Ivoire, respectively in the long run. A similar result was obtained by Shashi and Marcella (2010). However, this result contradicts the study of Noula et al. (2013) which reported that there is a negative but insignificant relationship between cocoa export and

Table 2. Unit root test using ADF.

Variable	ADF Level		ADF First difference		IO
	No trend	Trend	No trend	Trend	
Ghana					
lnGDPPC	2.680	0.224	-4.658***	-5.821***	I(1)
lnCOP	-1.616	-1.078	-5.298***	-5.726***	I(1)
lnCOEX	0.425	-1.570	-6.651***	-7.258***	I(1)
lnINFL	-3.552**	-5.109**	-	-	I(0)
lnEXR	-3.175**	-1.119	-3.214**	-4.272***	I(1)
lnLE	0.893	-5.507***	-	-	I(0)
Cote d'Ivoire					
lnGDPPC	-1.010	-2.351	-3.385**	-3.306*	I(1)
lnCOP	-2.055	-2.606	-5.852***	-5.814***	I(1)
lnCOEX	-0.986	-3.265*	-5.891***	-5.895***	I(1)
lnINFL	-4.354	-4.519***	-	-	I(0)
lnEXR	-2.309	-1.932	-4.779***	-4.771***	I(1)
lnLE	-4.224***	-3.324*	-	-	I(0)

***,**,*Statistical significance at 1, 5, and 10% levels of statistical significance, respectively.

Table 3. Bounds test results for cointegration relationship.

Model	F-Statistic	Critical value 99% bound		Critical value 95% bound	
		I(0)	I(1)	I(0)	I(1)
Ghana					
Fy(lngdppc, lncop, lncoex, lnexr, lninfl, lnle)	10.778	3.41	4.68	2.62	3.79
Cote d'Ivoire					
Fy(lngdppc, lncop, lncoex, lnexr, lninfl, lnle)	12.958	3.41	4.68	2.62	3.79

economic growth in Cameroon.

The study also found that exchange rate has a positive and significant effect on economic growth in Cote d'Ivoire in the long-run. This implies that an increase in exchange rate causes the Ivorian economy to rise by 0.94%. This is similar to the finding of Verter and Becvarova (2016). However, Ojide et al. (2014) found a negative relationship between exchange rate and economic growth in Nigeria. Although there was a negative relationship between exchange rate and economic growth in Ghana, it was found to be insignificant.

Apparently, the sign of inflation was consistent with economic theory in Ghana, as the relationship between inflation and economic growth was negative in the long-run. As a result, the growth rate of the Ghanaian economy will decline significantly by 0.03% for a 1% rise in the rate of inflation. However, inflation exhibited a significant positive influence on economic growth in Cote d'Ivoire. The study results contradict the findings of Noula et al. (2013).

Eventually, the study established a significant positive long-run relationship between life expectancy and economic growth in Ghana. This implies that a year increase in life expectancy in Ghana will increase economic growth by 8.85%. However, unrelated outcome was observed in the case of Cote d'Ivoire; life expectancy was found to relate negatively to economic growth. It was statistically significant at 1% level and exerts a negative impact of about 7.78% on growth for a year increase in life expectancy. The finding for Ghana concurs with most outcomes in several empirical studies. Particularly, Barro (1996) and Upreti (2015) who unveiled that there is an evidence of a positive association between longer life expectancy and the growth rate of GDP per capita in developing countries.

Short-run relationship

The short run effects of independent variables on economic growth are shown in Table 5. The first variable which is cocoa price was positively and negatively related

Table 4. Estimated ARDL long-run coefficients.

Regressor	Dependent variable: lnGDPPC					
	Ghana			Cote d'Ivoire		
	Coefficient	T-statistic	P-Value	Coefficient	T-statistic	P-Value
lnCOP	-0.012	-2.012	0.063	0.087	1.285	0.215
lnCOEXP	0.084	4.230	0.001	0.163	2.067	0.053
lnEXR	-0.036	-1.146	0.270	0.945	4.386	0.000
lnINFL	-0.029	-2.518	0.024	0.124	2.743	0.013
lnLE	8.852	4.614	0.000	-7.784	-5.408	0.000
C	-30.195	-3.883	0.001	34.023	5.964	0.000

Table 5. Estimated ARDL short-run coefficients and the error correction estimate.

Regressor	Dependent variable: ΔlnGDPPC					
	Ghana			Cote d'Ivoire		
	Coefficient	T-statistic	P-Value	Coefficient	T-statistic	P-Value
ΔlnCOP	-0.002	-1.562	0.139	0.027	1.214	0.241
ΔlnCEX	0.038	4.484	0.000	0.051	1.866	0.078
ΔlnEXR	0.029	1.918	0.074	0.377	8.612	0.000
ΔlnINFL	-0.013	-3.003	0.009	0.021	3.107	0.006
ΔlnLE	29.094	2.436	0.028	-54.323	-6.023	0.000
CointEq (-1)	-0.450	-5.067	0.000	-0.315	-4.968	0.000
R-squared		0.865			0.921	
Adjusted R-squared		0.748			0.873	
Durbin-Watson		2.164			2.468	
F-statistic		7.379			19.141	
Prob.(F-statistic)		0.000			0.000	

to economic growth for Cote d'Ivoire and Ghana respectively and was insignificant in impacting on economic growth in the short run. The coefficients of cocoa price depict that a 1% rise in cocoa price will lead to an increase in economic growth by 0.03% in Cote d'Ivoire, but leads to a decline in economic growth in Ghana. Cocoa export as could be seen from Table 4 exhibited positive sign suggesting that it is positively related to economic growth in Ghana and Cote d'Ivoire in the short-run. Cocoa export was significant with the capacity to raise economic growth by 0.04 and 0.05% for each 1% increase in cocoa export in Ghana and Cote d'Ivoire respectively. This result is similar to the finding of Shashi and Marcella (2010), but it contrasts the outcome of Noula et al. (2013).

Inflation was once again in consonance with the a priori expectation and theory in the case of Ghana. Inflation was significant at 1% and demonstrated an inelastic effect. The coefficient of inflation -0.012965 shows that 1% increase in the rate of inflation will lead to a proportionate decrease in economic growth by 0.01% in the short run. But, in the short run, inflation was positive and significant in relation to economic growth in Cote d'Ivoire. The estimated coefficient was 0.021345 and it was significant at 1% significance level. The implication is that an increase in inflation rate positively and significantly influences economic growth in Cote d'Ivoire.

The study also exhibited that, in the short run, exchange rate was found to have a significant positive impact on economic growth in the two major cocoa exporting countries (Cote d'Ivoire and Ghana). This is in line with the finding of Verter and Becvarova (2016).

Life expectancy has a negative and significant association with economic growth in Cote d'Ivoire, whilst in Ghana, it was found to augment economic growth at 5% significance level. An improvement in life expectancy by one year improves the level of economic growth by over 29% in the case of Ghana, meanwhile, a year upsurge in life expectancy causes economic growth to decline by 54% in the situation of Cote d'Ivoire. This makes human health the most significant variable in determining economic growth in Ghana.

Conclusion

Some West African countries have extensive access to natural resources and rely heavily on revenues from the export of these primary commodities. The heavy dependence of Ghana and Cote d'Ivoire on revenues from the exportation of cocoa raises the possibility that these economies are vulnerable to external commodity price fluctuations. This paper sought to examine the relationship between cocoa price, real exchange rate and economic growth using time series data for the period 1980 to 2011.

The study established that cocoa export, exchange rate, and inflation had a positive influence in determining economic growth in Cote d'Ivoire. But, cocoa export and life expectancy were identified to have a positive long-run effect on economic growth in Ghana. It was also found that there is a negative long-run relationship between cocoa price and economic growth in Ghana.

With the exception of life expectancy, the study found that, in the short-run, cocoa export, exchange rate and inflation had a positive and significant impact on economic growth in Cote d'Ivoire. In the situation of Ghana, the short run error correction model emphasized that cocoa export, exchange rate, and life expectancy had positive effect whereas inflation impacted inversely on economic growth. Eventually, the results suggested that, in the short-run, cocoa price has an insignificant impact on the performance of Ghanaian and Ivorian economy respectively.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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