Rubber plantation in the Atewa landscapes - Ghana.

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CHAPTER 10

Natural Rubber (*Hevea brasiliensis*) Production and Prospects for Sustainable Economic Development in Africa

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Highlights

- Natural rubber production plays a major role in the livelihood of thousands of rural African farmers both directly and indirectly.
- Natural rubber performs three main functions in the global African economy: in the areas of raw materials for the agro-based industries, foreign exchange earnings and employment to a sizeable segment of the farming population.
- The various government contributions to rubber production in Africa were generally very low, with the global production of Natural Rubber growth rate for Africa placed at only 2.2%.
- The various African governments should facilitate a vibrant rubber sector dominated by smallholder farmers who can sell their products to free non-monopolistic markets within their vicinity.

1. Rubber - *Hevea brasiliensis*

Natural Rubber (*Hevea brasiliensis*) is a fast-growing upright tropical tree mainly cultivated for its latex production, a milky plant liquid, which defends the plant against insect intruders (Figure 10.1; 10.2). The harvested latex usually serves as a basic raw material for various products. It can be used as a "plantation crop" grown and harvested over large uniform areas (3,000 to 5,000ha) around a central treatment unit to allow for a relatively rapid industrial handling after harvesting (Verheye 2010). The globally dominant mode of rubber production is as a smallholder crop in monocultures, modified forest (agroforest) or planned mixed crop systems.

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Figure 10.1: *Typical rubber plantation in Nigeria*

Figure 10.2: *Mature rubber plantation undergoing harvesting of latex.*

The rubber plant is part of the spurge family *Euphorbiaceae*. The milky latex extracted from the Hevea tree is the primary source of natural rubber. The latex is obtained through a process of "tapping" the plant by wounding the bark. It takes a relatively slow and time-consuming process to tap a rubber tree. Therefore, it must be done in an environmentally friendly way so that the tree remains in good health for its average economic life of around 30 years.

Tapping of rubber trees starts when the girth reaches 40 to 59 cm, in the 5th to 7th year after planting, depending on climate and soil conditions. A special knife is used to incise the bark to wound the resin canals without damaging the active growth zone (cambium). Depending on the tapping strategy and the degree of bark recovery, the economic life span of rubber trees ranges from 25 to 30 years; thereafter, the trees are felled and replanted (Coulen et al 2017). In contrast, in some agroforest systems, internal rejuvenation of rubber trees occurs within the stand, leading to uneven-aged trees and avoiding the replanting gaps in productivity.

Rubber production levels are not constant, as the tapping intensity can respond to market signals and household level labour availability. Yields also vary with planting material, climatic and soil conditions, and crop management. Modern clones (reproduced by grafting on selected rootstocks) yield on average between 1 and 1.5 tons of dry rubber per ha in industrial plantations in Asia (with peaks up to 2.2 tons/ha) and 1.5 to 2 tons (with maxima up to 2.5 tons) in Africa. On smallholders' plantations, yields are about 80% of industrial plantations (Verheye 2010). As labour is a major part of production costs, however, the latex yield per labour day is a more relevant economic indicator than yield per ha. Data for Asia suggests that the differences between production systems are much smaller when expressed in this metric. Unfortunately, there is no authenticated data of this metric system in African rubber production circles.

2. Origin and distribution of Natural Rubber in Africa

The rubber tree is native to the tropical rainforest of the Amazon basin and the Guianas (Ghani and Wessel 2000). It is widespread in the northern part of South America (Brazil, Bolivia, Colombia, Peru) and was later introduced into South-East Asia (95% of current latex production is in this region) and Africa.

Rubber seedlings smuggled out of Pará state in Brazil became the parent planting stock for all rubber plantations developed in present-day Malaysia and other Southeast Asian countries at the end of the 19th century. Rubber has since been planted in a number of tropical countries as a plantation crop. Currently, rubber is grown in Thailand, Malaysia, Indonesia, India, Sri Lanka, Vietnam, Laos and China, in Asia, and Cote d'Ivoire, Nigeria, Cameroon, Liberia and Gabon in Africa (CABI 2019, FAO 2017, 2021).

Hevea was introduced in Africa early in the 20th century. It was introduced into Uganda and Nigeria in 1903, Congo in 1904 and Liberia in 1924 by the Firestone Tyre and Rubber Company. The earliest experience with rubber in Africa was one of history's worst colonial excesses in the Etat Independent du Congo ruled by King Leopold of Belgium (Anstey 1971). Nigeria was the biggest producer of natural rubber from 1961 (58,000 tons) to 1966 (73,500 tons), with Liberia being the runner-up (FAO 2017). Sporadic natural rubber production in Africa started between 1883 and 1905, while modern cultivation of natural rubber is just about 50 years old due to the effect of the Second World War, which slowed down the process.

3. Production and contribution of natural rubber to Africa's economy

Africa's contribution to the production and consumption of Natural Rubber is still very low as the continent only accounts for 5% of world supplies and only about 2% production growth rate. This is against 90% supply from South East Asia with about 6.2% production growth rate and 6.4% consumption growth rate (Umar et al 2011). At present, rubber plantations and small-holdings are scattered along the seaboard from Guinea-Bissau to West Cameroon, where rainfall is adequate and soil conditions are right (Gaille 2018). Côte d'Ivoire ranks first in natural rubber production in Africa with a production of 664,695 tons and 4th in the world, followed by Nigeria, which is second in Africa (149,691 tons) and 13th in the world (FAO 2021, NationMaster.com 2021).

Rubber world price transmission to domestic markets in Africa has not been widely studied. Existing studies are either not recent or focus mainly on cocoa and coffee or staple foods (Lloyd et al 1999, Jutting 2005, Soumahoro 2017). Only very scanty evidence has been found on how rubber world prices are transmitted to the African domestic market. However, studies by Ahoba and Gaspart (2019) in Cote d' Ivoire suggest that the world price and the producer price move together in the long run and the transmission process does not present asymmetry. In the long run, world prices are perfectly transmitted to domestic prices, and the short-run elasticity is about 0.75, which also means that changes in rubber world prices are highly transmitted to producer prices in the short run. It is unfortunate to note that the positive relationship between the two prices suggests that producers are also directly exposed to huge decreases in prices. This constitutes a threat to their revenue as producers are heavily exposed to world price fluctuations.

The case scenarios are different for the various African producing countries, as shown below.

3.1. Cote d" Ivoire

In Cote d' Ivoire, over 50% of their natural rubber production comes from smallholder producers. From less than 100 tons in 1961, the national rubber production reached 119,000 tons in 2002 and 270,000 tons in 2013 (Ruf 2012, Kouame 2015). In 2018 the country's rubber export was 5.7% global sales - US$752.6 million (Workman 2019). However, irrespective of the fact that the country alone produces about 50% of the whole African total production, it only holds a marginal share of the world market. Unfortunately, the Cote d' Ivoire producer price does not influence the world price as it is still a marginal producer worldwide with a contribution of around 2% of the world production (MINADER 2016).

3.2. Cameroon

Although smallholders represent about 80% of the total area and production of natural rubber in the world, the situation in Cameroon is quite different as they only represent 7.4% of the area planted and 5% of the national production. Most of the rubber smallholder plantations were created during the 1980s when the Cameroonian government launched two smallholder rubber development projects partly funded by the World Bank. The first one was implemented between 1978 and 1986 in the South-West province and the second one between 1982 and 1990 in the southern province. Two public agro-industries (CDC in the South-West and HEVECAM in the South, which was privatised since 1996) were the technical operators for the implementation of these projects. A total of 1,343 ha of smallholder plantations were developed. For the majority of these farms (902 ha), the plantations were settled by the farmers themselves on their land under the control and supervision of the estate (Chambon and Michels 2004).

3.3. Liberia

In 2010, 61% of Liberia's US$207 million in export earnings came from rubber (World Bank 2010). However, in 2019 it accounted for 16.5% of the total export receipts of the country, while in 2018, the country's rubber export was 1% global sales-US$126.2 million (Workman 2019). Rubber is currently Liberia's most important export commodity. It is estimated that more than 20,000 people are employed by commercial rubber farms, and up to 60,000 smallholder households are involved in the growing of rubber trees. However, no baseline study provides a definitive statistic. The Firestone natural rubber concession, covering almost 200 square miles, is the largest contiguous natural rubber operation in the world and the biggest private-sector employer in Liberia (ITA 2020).

3.4. Sierra Leone

In 2012, the government of Sierra Leone and China's Hainan Natural Rubber Industry Group announced a US$1.2 billion rubber and rice investment in Sierra Leone. The 50-year deal will utilize 135,000 hectares of land across 12 chiefdoms in Tonkolili, Moyamba and Port Loko districts. The deal is likely to catapult Sierra Leone into a leading position in the rubber production index for Africa, knocking Firestone in Liberia off of the grid. With 100,000 hectares of land for rubber, yearly output is estimated at 180,000 tons, second only to Cote d'Ivoire. The project estimates the creation of over 30,000 full time and 150,000 part-time employments with projected revenue to the government assessed at between US$50 to 100 million. The government of Sierra Leone itself will own a share of the investment in exchange for the land.

3.5. Ghana

In Ghana, the APRA Work Stream 1 data revealed that approximately 12% of 726 households in the baseline sample stepped out from oil palm production between 2017 and 2019. Those farmers voluntarily cleared their oil palm plantations to plant rubber, explaining that rubber cultivation was more economically rewarding and less involving in terms of input and labour costs. Others explained that incentives provided by rubber-buying companies, such as Ghana Rubber Estates Limited (GREL), were the reason for their shift away from oil palm to rubber. Some of the farmers also felt cheated by the oil palm companies (OPCs) and their agents through the adjustment of their weighing scales and low prices. Additionally, GREL also provided social infrastructure, such as schools and clinics, to the local communities in their areas of operation (Hodey and Dompae 2020).

3.6. Nigeria

In 2018, Nigeria's rubber export was US$ 41.8 million (0.3% global sales) (Workman 2019). In Nigeria, the small-scale rubber farmers account for about 85% of hectares of the total rubber plantations in existence (Umar et al 2011). Nigeria's annual export of 127,000 metric tons natural rubber brought in export earnings of US$ 37 million in 2017 (NEPC 2018). The government of Nigeria recently introduced the Economic Recovery and Growth Plan (ERGP: 2017-2020) as a road map to diversify its economy, which depended on crude oil sales with an emphasis on agriculture to create jobs, reduce food imports and support the growth of her GDP (Ejeh and Orokpo 2019).

Earlier, the government introduced a 12-year (2006- 2018) Rubber Initiative Plan for increased rubber production for local use and export through aggressive cultivation of new plantations and rehabilitation of old plantations to achieve a target of 360,000 ha, which outstandingly yielded 371,775 ha of harvested rubber plantations (FAO 2017, Umar et al 2010). The Rubber Research Institute of Nigeria (RRIN) genetically developed Nigerian rubber seedlings code-named NIG800 and NIG900 series with yields of 3,000 to 3,500 kg of dry natural rubber/ha/year when compared with imported seedlings from Southeast Asia countries, whose yields range from 900 to 1,600 kg dry natural rubber/ha/year (Umar et al 2010). The Nigerian seedlings are presently made available to small-scale rubber farmers and estate rubber planters for cultivation to address the challenges of low natural rubber production (Onoji et al 2021).

4. Economic importance of the crop

Rubber is one of the greatest natural commodities in the world, and its versatility makes it ideal for many different applications. Due to its elasticity, resilience, and toughness, among other properties, natural rubber is the basic constituent of many products used in the transportation, industrial, consumer, hygienic, and medical sectors.

4.1. History of Rubber utilization

The indigenous cultures of Mesoamerica were the first to use rubber. Latex from the Pará rubber tree was extracted to produce rubber to be used in making balls for the Mesoamerican ballgame. The Aztec and Maya cultures later started using rubber for various purposes like making waterproof textiles and containers. In the year 1770, Joseph Priestley discovered that rubber could be used to scrub off pencil marks on paper. Gradually, other uses of rubber were discovered, and its usage became popular across Europe. Trade soon started between the New World and Europe. Vulcanization (hardening by treatment with sulphur) was discovered in 1839 and led to more widespread use of rubber (Oishimaya 2017).

4.2. Local uses of natural rubber

Rubberwood is of medium density and light in colour but susceptible to fungal and insect attack unless treated chemically. It has traditionally been used as a cheap source of wood fuel in most of the countries where rubber plantations are abundant, such as for brick burning, tobacco curing etc. Two products obtainable from rubber seeds are the oil and the cake (Iyayi et al 2008). Even though rubber seeds are poisonous, they can be eaten as a famine food after local processing (Hong 1995, Sarawakian Local Delights 2016, Oluodo et al 2018).

4.3. Industrial uses of natural rubber

Tires and tire products account for 50% to 70% of natural rubber usage, making transportation the leading single sector of the major uses of rubber. Automobile tires, followed by truck and bus tires, make up the prime outlet for natural rubber. As the oldest use for rubber, today, more than 20 million tires are manufactured every year. During World War II, when access to the main rubber producing areas was restricted, ‘synthetic rubber’, based on fossil carbon sources, was developed – but it does not have the same range of applications. The natural rubber has a greater resistance to heat compared to synthetic rubber, making its use vital in some types of tires (Egwuatu 2013).

The rubber industry manufactures numerous useful items, including rubber matting, auto tires and tubes, vehicle parts (seals of windshield and windows, timing belts), conveyor belts, footwear, cables and wires. It is also used for hot water bottles, balloons, rubber bands, rubber flooring (particularly in gyms and kitchens), flexible hose and ducting products, rubber gloves, condoms and gaskets. For some of these products, the latex has to be directly processed, while for others, it can be locally coagulated and processed to clean and dried sheet or crumb rubber as an intermediate product. Industrial products such as industrial lining, transmission and elevator belts, bridge bearings, and consumer products such as golf balls, erasers, footballs, footwear, and other apparel accounts for the remaining usage of rubber (Brentin and Sarnacke 2009).

Rubber is made into articles as diverse as raincoats and sponges, bowling balls and pillows, electrical insulation and erasers. People ride on rubber tires and walk on rubber heels. Rubber is also used in toys, balls, rafts, elastic bandages, adhesives and paints. The rubber seeds, when processed, produce oil alkyd resins used for paints, soaps, skin cream and hair shampoo. Boiling removes the poison and releases the oil that can be used for illumination. The kernels (50%–60% of the seed) contain 40%–50% of a semi-drying pale yellow oil, used in soap making, paints, varnishes and insecticides, which are effective against houseflies and lice.

There is a growing interest in technical applications of chemically treated rubber wood for furniture factories, untreated wood for energy generation (as firewood and charcoal), and in the pulp and paper industry. Rubber wood is considered a source of cellulose nano-fibers which possess a vast range of potential applications in areas such as biomedical, electronics, packaging, nano-composite, gas barrier films, and optically transparent functional materials (Aigbodion 2017). Rubber woods are also known to have also been utilized for the production of parquet, panelling, wood-based panels (particleboard, cement and gypsum-bonded panels, medium-density fibreboard (MDF), kitchen and novelty items, sawn timber for general utility, packaging cases and pallets (Salleh 1984, Verheye 2010).

4.4. Renewable energy from natural rubber factories

The effluents (serum wastewater, etc.) from factories can be processed into renewable energy like biogas. Ahmad et al (2018) reported that rubber could be converted to renewable energy via hydrous pyrolysis. The heating value of the energy from natural rubber is suitable for domestic applications such as heat generation, as the biogas falls within the range of 18.6 to 26.1 MJ/m3 (Onoji et al 2021).

5. Challenges and constraints of natural rubber production in Africa

There are several challenges that are affecting the sustainability of natural rubber production in Africa. Natural rubber production is labour-intensive and requires a well-skilled workforce. Shortage and high cost of labor limit the sustainability of natural rubber production in Africa (Fenske 2013, Giroh et al 2013). In the past, majority of farm labor was gotten from an immediate and extended family member, but rural-urban migration has culminated into the scarcity of labor. Additionally, inadequate supply of raw materials (latex and cup lumps) to the processing plants, low levels of mechanization for yield improvement, lack of knowledge about suitable rubber variety for specific areas, lack of technique to enhance output without necessarily increasing input and lack of knowledge about latex storage and processing practices (Fenske 2014). Research on rubber is still weak due to inadequate funding and agricultural extension delivery services is poor depriving rubber farmers of knowing the modern technique in rubber farming and processing.

The long gestation period (6 years) of natural rubber, which deprives the farmers of sustainable income during the immature phase, as well as, uneconomic land size (smallholder farm sizes) available for plantation establishment is a major challenge to sustainable natural rubber production (Michael 2006)**.** In order to overcome this, farmers resort to intercropping rubber with short duration annual and perennial crops in the first 1-3 years of the plant life to offset the 6 years of the income gap between the time of establishment and latex production (Abraham 1980, Zainol et al 1993)**.** Another important challenge to rubber production sustainability in Africa is pests and diseases (Bjornlund et al 2020, Ubani et al 2020). Rubber is grown mainly as a monoculture, and the effect of pests and diseases are more severe in monocultures. Pests and diseases reduce the yield for rubber farmers. Farmers spend huge amounts of money in purchasing chemicals to control weeds, insects, pests and diseases in rubber production, thereby reducing their profit (Agwu 2006, Ansong et al 2021). These chemicals are also harmful to the farmers and their environment (Ogbebor 2013, Häuser et al 2015). Most of the rubber trees are very old and have gone past their economic thresholds. Climate warming and rainfall unpredictability have an impact on rubber production. This can lead to the shift in a climatically favorable area for cultivation, slow growth rate, decrease in the field survival of young plants and increase in the impact of pest and disease and the emergence of new pests and diseases (Golbon et al 2018, Pinizzotto et al 2021). The impact of climate change on rubber production in Africa is not well documented, and more research needs to be carried out to understand the impact. However, studies in Asia reported that rubber production has a severe impact on ecosystem functions such as soil carbon storage, aboveground biomass and below-ground biomass. This can be improved by including agroforestry or polyculture, integrated pest management, cover cropping, and mulching (Gitz et al 2020, Singh et al 2021). Also, expansion in rubber production in Africa will involve huge deforestation, which has a severe impact on climate.

Rubber farmers in Africa encounter financial challenges such as high cost of capital, withdrawal of subsidies from farming inputs, inadequate provision of credit facilities to the smallholder farmers resulting in lack of fund to expand rubber plantations and lack of a medium, long-term facilities and high cost of credit to finance private rubber plantations (AFD 2009). These financial challenges have prevented the rural poor from venturing into rubber production. In the past, few countries in Africa were involved in the production and export of natural rubber. However, recently, other countries are now involved, thus increasing competition in the market and also competition from the main natural rubber producers in Asia. Locally, distance from the farm to the market, characterized by bad roads and high cost of transportation, negatively affect natural rubber production in Africa (Chambon and Michels 2004). The low bargaining power among villagers and traders is also a major market challenge.

Poor monitoring, evaluation and implementation of government policies and farming programs resulting in abrupt abandonment of several government support programs on rubber negatively affects rubber farmers in Africa. Most government programs are abandoned by the next political holder. Mismanagement of funds and financial corruption are key policy challenges within the sector (Wangwe et al 2014). Also, agricultural insurance frameworks are lacking in place to mitigate losses during natural disasters. The government has failed to provide basic amenities such as water and electricity for rubber processing within villages.

6. Potentials of Rubber Sustainability in Economic Development of Africa

There are several socio-economic benefits of rubber, such as diversification of agricultural products, increase in income levels for farmers, employment opportunities in the farming communities, foreign exchange earnings, and enhancement of women economic emancipation. Rubber, which is an internationally traded agricultural commodity with high demand all over the world, plays a major role as a forex earner and is a major contributor to the growth of the national economies of many African countries (Esekhade et al 2019). Natural rubber is a strategic material as it cannot be replaced in many important applications due to its outstanding elasticity, resilience, flexibility at low temperatures, resistance to abrasion, impact and corrosion, facile adhesion to textile and steel and to its impermeability, insulating properties and ability to disperse heat.

The potentials of rubber sustainability to the agricultural sector and overall economic development are immense. These include:

- Guaranteed supply of rubber products to utilization factories or export to consumer countries stimulates expansion in farm production activities to meet the demand target
- Processing activities that are initially labour-intensive can in the long-term conform to the dynamic comparative advantage of most developed nations; smallholder farmers will escape from the syndrome of producing low value and poor quality products
- Value addition to rubber produce may lead to export-oriented industrialization through chain upgrading
- Strong linkages between crop producers and end-users not only generate added value but also create employment opportunities in rural areas, thereby contributing to economic growth and poverty reduction
- Generate a vacuum for wealth creation and improvement in the socio-economic welfare of the citizenry.

6.1 Social and Rural Development

Large-scale estates, when managed in an open and socially-friendly way, can be major tools in rural development. The rubber processing factories do not only provide work for quite a number of labourers but also actively stimulate the establishment of schools and dispensaries, the development and maintenance of a proper road network, the partial or total reconstruction of local villages and improvement of housing facilities in general, and the installation of a safe-drinking water network. The Southwestern region of Ivory Coast around the local centers of

San Pedro, Sassandra, and the Liberian border has over the past 40 years been converted from an almost inaccessible, dense tropical forest area into a well-developed part of the country almost exclusively as a result of the activities of rubber and oil palm estates (Verheye 2010).

6.2. Wealth creation from rubber wastes

The disposal of waste used tires, in particular, is a major concern to waste management authorities in African countries because it is seen as a service to be rendered by the government. However, from the perspective of sustainable development and the need for a cleaner environment, it is a collective responsibility of every individual in society (Oh and Hettiarachchi 2020). The shortcomings of the conventional approach to managing the disposal of waste tires can be addressed through the use of more friendly green technologies to recover material and generate energy for domestic and industrial applications. With the fast depletion of natural resources and to meet stringent emissions standards, reduction in waste tires by reincorporating them into production processes will add value to what was hitherto considered valueless (Ramirez-Canon et al 2018).

Waste valorization via thermochemical process is a promising method used to create wealth from waste tires because of its simplicity, cost-effectiveness, and high purity of products. Pyrolysis is a valorization process that can be used to recover energy and value-added products from waste tires due to challenges involved in tire recycling and reuse (Kan et al 2017, Smelik et al 2015). The pyrolysis process conditions can be optimized to favour products of interest such as bio-char, oil (C5-C24), and gases (C1-C4) (Osayi et al 2018).

Another technology of interest to manage solid municipal waste and waste tires disposal is waste incineration. Major products recovered from the process, such as bottom ash and fly ash (used after pretreatment to remove heavy metals, salts, chloride, organic pollutants, etc.), are sources of chemicals and valuable compounds such as CaO, SiO2, Fe2O3, and Al2O3. These compounds could find applications in the cement and concrete factories, ceramic industry, stabilizing agent, adsorbents and zeolite production. Most cement factories produce CaO from the thermal decomposition of CaCO3 generating large emissions of CO2, a greenhouse gas (GHG) contributing substantially to global warming. Therefore, the production of CaO through combined waste (tire, solids, etc.) incineration is considered environmentally friendly, as the process produces nitrogen, phosphorus, and potassium from the ash for fertilizer production (Lam et al 2010).

Waste tires can be shredded into crumb rubber and processed through ambient grinding or cryogenically turbo-milled (Lehigh technologies) to produce very fine micro-particles of free-flowing rubber materials known as micronized rubber powder (MRP). Studies have shown that MRP can be efficiently and economically used as rubberized-asphalt concrete when mixed with conventional aggregate materials for road construction. The MRP utilized in road pavements results in longer-lasting and enhanced road surfaces, reduced road maintenance, cost-effectiveness over long and short braking distances, skid resistance and better tire traction (RMA 2009). Other promising areas where MRPs could be applied include athletic and recreational facilities such as ground cover for sports (e.g. football fields), playing fields, running tracks, and children playgrounds. It can also be utilized in the production of roof coatings, moulded and extruded products, adhesives, asphalt, plastic resins, sealants, brake pads and brake shoes with enhanced properties (Kim and Burford 1998, RMA 2009). Therefore, proper understanding and utilization of MRPs can result in significant and environmental benefits when this green technology is deployed to create a sustainable economy.

6.3. Conceptualizing green rubber systems

The green rubber systems can be defined as rubber production and trade that support the maintenance or enhancement of ecosystems and contribute to intra-household empowerment of women and poverty alleviation at both the household and community scales. It can potentially be seen as a goal for the development and evolution of rubber in the continent. This ideal form of green rubber production would be smallholder-controlled production, using agroforestry or mixed cropping methods, and organized through a production or marketing cooperative, receiving technical and financial support from the public and private sector.

Smallholder production has the greatest potential to provide benefits directly to the household and alleviate poverty. Smallholder rubber is not just an idea – the majority of rubber production in the largest producer countries comes from smallholders: 93% of the sector in Malaysia, 90% in Thailand, 92% in India and 85% in Indonesia (Witness 2014). Not only can smallholder production increase incomes, but it can also do so in a way that empowers households and communities as they maintain control over the production process, most importantly over their lands and labor; in comparison with the loss of power, mainly experienced when working as wage laborers on large-scale plantations. Smallholder rubber production has been shown to be more effective when organized in production and marketing cooperatives (Witness 2014). Cooperatives have played an important role in the rubber industry of India, which is the 4th largest producer of rubber globally (Indian Natural Rubber 2011). The cooperatives helped to improve the efficiency and productivity of rubber smallholder systems, enabling them to achieve a lower cost of production and better prices for their products compared with non-members. However, research by the World Agroforestry Centre (ICRAF) has shown that high yielding rubber clones can be combined with swidden cultivation without loss of latex productivity (Wibawa et al 2006).

One of the main benefits of agroforestry and mixed cropping systems is that they diversify income and subsistence, thereby increasing the economic resilience of the farming system. Farmers can rely upon other trees, crops or livestock for income or consumption when rubber prices are low, thus creating a buffer for farmers' incomes against price fluctuations. The other main 'green' dimension of agroforestry and mixed cropping systems is their ability to maintain and even enhance ecosystems. Such systems have a positive impact on soil quality, which leads to increased tree productivity – intercropping improves the soil due to nitrogen inputs from other crops, thus improving the performance of the trees (Douangsavanh et al 2008).

According to Cardinale et al (2011), rubber trees yield more when grown with other crops than on their own in a monoculture plantation because the fertile topsoil is lost in monocropping due to erosion, leading to lower yields overall and over time. Small-scale and diverse rubber systems can also reduce the detrimental effects of monoculture rubber plantations on species diversity and ecosystems. Species diversity is higher in agroforestry systems than in monocultures, and studies have shown that agroforestry systems can play an important role in the conservation of primary forest species (Cotter et al 2009). Finally, mixed cropping systems, such as a tea–rubber intercropping system, have been shown to sequester atmospheric CO2 and increase soil organic carbon better than monoculture rubber (Zhang et al 2007).

7. Discussion and relevance for Africa

Globally there is more rubber production capacity than current demand, and farmgate prices (and FreeOnBoard crumb rubber in international trade) are low. Since rubber is labour intensive and hardly open to mechanization, latex yields per day of work have not kept up with productivity increases in other sectors. Therefore, the only chance for African rubber would be that SE Asian wage rates phase out rubber production and shift to other crops of lower labour intensity. Africa is also not known to be a major utilizer of natural rubber raw materials due to their low state of industrialization. Most of the countries depend on finished rubber products imported from developed nations.

Rural areas in Africa are essentially characterized by missing financial markets, and this reduces the natural rubber producers' ability to deal with the consequences of price fluctuations. It is therefore very pertinent for policymakers to introduce price compensation mechanisms to make up for such unprecedented world price fluctuations. The result of the various surveys carried out in Africa has shown that government contributions to rubber production in the continent were very low. Hence, governments could put in place efforts like generating loans for small scale farmers who are willing to venture into huge plantation production but who lack capital for investment. Finally, if the rubber industry is well re-positioned, this capital and labour-intensive industry has the capacity to create wealth, enhance the non-oil sector's forex earnings, and greatly reduce crime and poverty.

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