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Review

Organic production and its market support policies

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Populations around the world, especially in developed countries, have adopted a more conscious food consumption than that practiced conventionally, in their search for a better quality of life. In this scenario of concern about food, the organic products market is highlighted in the face of the high consumption of food produced with agrochemicals and agricultural inputs. In the last few years, there has been a significant market growth, moving 91.2 billion dollars. The present paper aimed to identify several organic production support programs, especially the Brazilian Food Acquisition Program (PAA). To this end, we used theoretical references about the theme, prioritizing the consultation of scientific articles and data from FiBL (Research Institute of Organic Agriculture). Results help understanding the increase in consumption, and they are associated with public policies that have been present in different parts of the world, more significantly in Europe and USA. However, it is necessary to note that support programs for the sector must be flexible and adapt to local capacities. It is worth emphasizing the importance of organic production units in Brazil, which have consistently increased the country's production, with direct support from PAA, and benefiting from the use of local family farming products in the National School Nutrition Program (PNAE).

Key words: Global organic market, support policies, organics in Brazil.

INTRODUCTION

Seeking a considerable quality of life, populations from various parts around the world have adopted a more conscious food consumption than that practiced conventionally. It is in this scenario that a concern about eating habits emerges as a highlight, especially with the appearing of a possible alternative in relation to the high consumption of food produced with agrochemicals and agricultural inputs: the organic products market.

Organic farming seeks a balance between a reasonable yield and a good quality of products and concerns itself with generating minimum/limited environmental impact (Zanen et al., 2008). It is understood that organic food are those derived from a more balanced production system, because they do not make use of agrochemicals and mineral fertilizers. Consequently, organic production reduces conventional farming environmental impacts, and moreover, considers social issues in its productive cycle, as it propitiates the small farmer's permanence in the rural area, reducing exodus, poverty and misery in cities.

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Studies from FiBL – acronym for the name in German *'Forschungsinstitut für biologischen Landbau'* that means Research Institute of Organic Agriculture (2018) – point out that organic farming has become a highlight worldwide in recent years after the production of organics moved 17.9 billion dollars in the world economy in 2000 and reached 91.2 billion dollars in 2016, an increase of more than 500% within fifteen years (corresponding to US$ 73.3 billion).

In this context, the present study aimed to identify and present characteristics of organic production support programs around the world, and especially in Brazil. In order to do so, searches for theoretical references approaching on the theme of the present work were carried out, prioritizing the consultation of scientific articles and FiBL data. This paper is designed for the stakeholders on organic production and how public policies act on the market for these products.

BRIEF CONTEXTUALIZATION ON ORGANIC FARMING

Near the end of the nineteenth century, Von Liebig introduced the practice of chemical fertilization in agricultural activities. At the time, several scientists questioned Liebig's position, claiming that biological processes were indispensable to maintain soil fertility. Discoveries of French scientist Louis Pasteur made it possible to prove the relevance of certain living organisms in the organic matter decomposition, as well as in nitrogen gas biological fixation processes. In such scenario, in the year of 1881, Darwin publishes the result of his researches on the function of earthworms in vegetable humus production (Escola and Laforga, 2014).

Pasteur's and Darwin's researches aroused other researchers' academic instincts in the field of agronomy. The head of the Soil Management Division of the United States Department of Agriculture, R. H. King, publishes an article in 1911 where he describes his observations on Oriental agricultural practices, which led him to conclude that those peoples could keep a permanent and sustainable agriculture. Later on, Albert Howard conceived the pillars of organic agriculture in their current forms, that is, grounded on sustainability ideals, balance and low dependence of outputs. His researches unfolded between 1905 and 1930 in India, where the scientist demonstrated that several living processes that are dynamic and fundamental to the health of plants occur in soil (Escola and Laforga, 2014).

Practices that exalted organic fertilization have for a long time been belittled and trivialized. In 1960, environmental damages coming from practices considered as modern (with the intense use of agrochemicals and pesticides) become more visible; thus, in the 1970s, alternative practices gained new understandings and curiosities raised. Despite the advance, it was only in the decade of 1980 that organic farming gained some credibility, as scientists increasingly started to take interest in more sustainable practices. Even scientists that did not support organic farming were aware of its importance (Kristiansen and Merfield, 2006).

In 1984, the United States Department of Agriculture (USDA) already recognized the importance of organic practice and conceptualized it as a production system that avoided or eliminated the use of fertilizers and the like. According to USDA, organic farming systems are based on crop rotation, organic fertilizations, natural minerals for plague control, among other practices considered sustainable. After about a decade since the growing interest on this topic, the volume of information increased allowing the publishing of Nicolas Lampkin's book, "Organic Farming", in 1990-a landmark for organic farming (Kristiansen and Merfield, 2006).

In this scenario, organic farming gained attention both from the academic community as well as from public policy makers, consumers and environmentalists of that time. It is in such a moment that the first organic farming support policies come up. However, it was not a simple task, as it was extremely complex to conciliate social and consumption aims in the face of market interests (Stolze and Lampkin, 2009). On the other hand, the academic milieu was becoming more favorable to the study of this area, which propitiated a "boom" of researches, many of which unfortunately not presenting effective results, for they only distinguished organic from non-organic farming, without any contribution to organic farmers (Lockeretz, 2002). Because it is a relatively recent field, the theme can still be a lot explored, but in a conscious way, without losing its ideals and the flexibility of adapting to different contexts where organic practices are included.

ORGANIC FARMING IN THE INTERNATIONAL CONTEXT

Studies demonstrate that organic farming and consumption have significantly increased in recent years. Increase that was intensified in the turn of the century, with the organic certified lands growing a total of 20 million hectares throughout the world between 2000 and 2008 (Willer and Kilcher, 2010). In this sense, it is important to mention what is regarded as the main differences between conventional and organic farming models (Table 1).

It is evident that organic farming seeks a balance between reasonable yield, quality of product and minimum environmental impact. An example of this are the inputs utilized, which are mostly composting waste and natural fertilizers (Zanen et al., 2008). Moreover, organics can generate profits between 50 to 100% higher when compared to conventional production, which makes them attractive to the small producer (Darolt and Skóra Neto, 2002). By 2016, organic production had 2.7 million

Table 1. Distinction between conventional farming and organic farming.

Conventional farming	Organic farming
Centralization of power and control in multinationals.	Decentralization of power, local and diversified control.
Dependence on numerous sources of external energy and services stemming from agribusiness.	Little dependence on inputs from outside of the property and the agribusiness complex, including rural credit.
Dominance over nature, and eternal struggle against nature to extract benefits for the human species.	Harmony with nature. Man and nature are inseparable and interconnected.
Based on specialization, plants and animals' genetic basis reduction and monoculture.	Based on practices that stimulate biological diversity at all levels of the production system.
Natural resources are treated as inexhaustible.	Commitment to natural resources conservation in the long term.
Competition is seen as a positive aspect for agriculture and society as a whole.	Importance of cooperation between agriculturists and the need for rural communities.

Source: Adapted from Beus and Dunlap (1990).

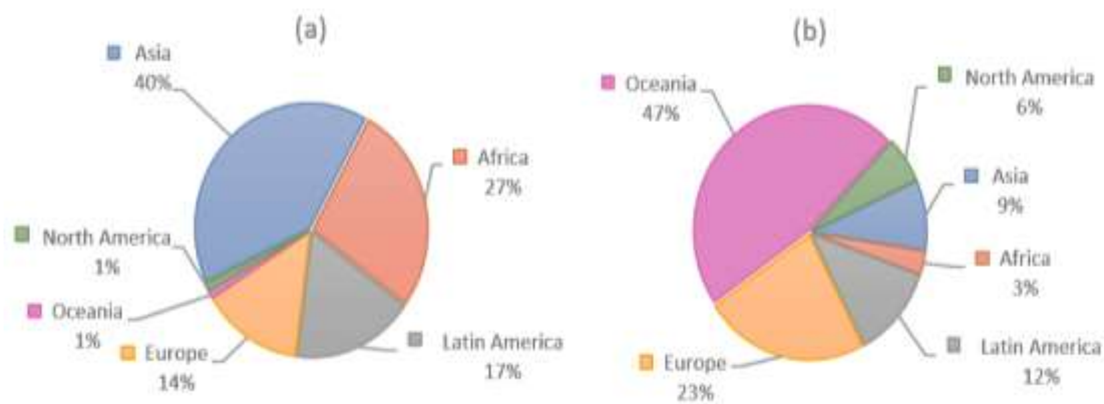

Figure 1. (a) Distribution of organic farmers by continent; (b) Distribution of organic agricultural lands by continent. Data from 2016.
Source: Adapted from FiBL; IFOAM (2018).

of producers worldwide, totalling 57.8 million hectares of land. However, the distribution of these organic farmlands across continents differs greatly from where organic producers are concentrated, as shown in Figure 1. A highlight is the Asian continent, where we find the greatest number of these farmers (40%), followed by Africa (27%), Latin America (17%), Europe (14%), Oceania and North America (1% each).

It is important to look more attentively at the African continent, as in spite of its low quantity of organic agricultural lands (only 3% of participation in total world lands aimed at organic farming) (Figure 1b), it presents high participation in production, with 27% of the world's organic producers (Figure 1a). According to data from UN, organic exports stemming from Africa grew from US$ 4.6 million in 2002/2003 to US$ 35 million in 2009/2010, a growth that was only possible with crop yield increase in countries such as Burundi, Kenya, Rwanda, Uganda and Tanzania. In this sense, organic farming features an opportunity for export in Africa. Nonetheless, financing for the sector has become more difficult in the last five years, according to data presented by the United Nations Conference on Commerce and Development (UNCTAD) (ONU, 2016).

In spite of the large African organic production, organic products are hardly certified in this continent, as in some countries, there are difficulties in implementing such activity (Terrazan and Valarini, 2009). The recent scenario shows a still incipient progress in the African continent (total of 54 countries), showing only one country with regulations fully implemented, one country with incomplete regulations implemented, seven countries that are in the process of regulation and eleven countries with a standard for regulation but without legislation on organics, as demonstrated in Table 2.

Gudynas (2003) highlights that until 2003, organic certification was still a problem, with many countries presenting their own certification agencies, in some cases with the support of the state and others, such as autonomous enterprises. An example of this is Malaysia, a country that has potential for organic production, but lacks in government support. In 2003, a certification

Table 2. Organic regulation by continent or region.

Continent/Region	Regulations fully implemented in the country	Regulations not fully implemented in the country	Countries in the process of regulation	Countries with a national standard but without regulations
Europe	37	2	3	-
Asia and Pacific Region	21	4	6	22
Americas and Caribbean	18	3	2	-
Africa	1	1	7	11

Source: Data from FiBL; IFOAM (2018).

scheme was created to support the internal market. The goal consisted in facilitating organic production certification in this country, encompassing all production stages (Tiraieyari et al., 2014). Today there are numerous organic farms in this country, and implicit in these initiatives is the minimization of harmful effects on the environment, health and organic farmers' safety (DOA, 2007).

In 2001, Department of Agriculture (DOA) identified only 27 organic agriculturists in Malaysia in relation to a total area of 131 ha. After implementation of the certification scheme, the number increased in 2010 adding up to a total of about 42 certification holders, who occupied 1130 ha of farmlands. In 2013, 89 farms adopting the organic production system were found to occupy almost 1634 ha of lands; but among these accounted areas, only 49 farmers had a valid certification, while 40 agriculturalists presented expired certifications (Tiraieyari et al., 2014).

Despite an increasing organic production in Malaysia, the process of certification is very costly and complex, which consequently leads to the rising prices of products. Organic cultivation ends up restricted to vegetables and a few fruits. The market is also very limited, as local production has high prices and so does its commercialization. These factors discourage local farmers from producing organics (Ahmad, 2001).

One of the big problems faced by Malaysia in the organic sector is the issue of land access and ownership. The country has adopted temporary occupancy licenses (TOLs) in the region of Cameron since the beginning of the 1980 decade. According to this system, agriculturists can cultivate the land temporarily, with government renewal of concession taking place annually. In this way, farmers lose part of their motivation to invest without the safety of property ownership at the end of a year (Tiraieyari et al., 2014). Other problems are listed, such as scarcity of work force, since activities on the field are carried out manually, demanding a large number of workers; lack of training and extension services; lack of marketing related to raising awareness of organic products consumption benefits, along with matters concerning commercialization in the agriculturists' association. Sales to neighbour countries, for example Singapore, are almost impossible; that is because the country does not import organics with the Malaysian seal.

An example addressed by Flaten et al. (2010) is Norway, where many farmers have been abandoning organic production, stating as their main reasons the excessive bureaucracy, high cost of the certification process, and also there is a constant regulation change allied to these. That generates uncertainties as to what the government will do in the future and might demand new adaptations on the part of agriculturists.

Despite this, data demonstrate that about 57.8 million hectares were aimed at organic products production around the world by 2016. That means to say that the quantity of agricultural lands aimed at organic farming worldwide is constantly rising and has presented increase of more than 420% since 1999 (FiBL; IFOAM, 2018).To visualize such event, Figure 2 shows the growth of organic agricultural areas by continent over the years, stemming from the increase of recognition (governmental and civil) of the environmental, social and economic benefits of sustainable agricultural practices. It is noted that the quantity of organic agricultural lands has been growing on all continents. Oceania, for example, presented the growth of more than 18 million ha the most significant increase in the period between 1999 and 2015 and holds the first position in the ranking of continents with greater quantity of organic agricultural areas. Followed by Europe, which increased its organic lands by almost 9 million ha, and Latin America, in the third position, with little more than 5 million ha of growth in that period. The other continents/regions presented increase of less than 5 million ha.

In this context, Figure 3 shows the ranking of countries with the largest organic agricultural areas in 2016, with Australia as a highlight, with the largest and most significant organic farming area of the world, comprising 27.15 million ha with organic areas. In general, studies of 2001 revealed that Australia was already ranked as the place with the greatest number of organic agricultural lands, with approximately 7.6 million ha. Currently, after Australia is Argentina with 3.01 million ha, followed by China, which surpassed the United States and its third

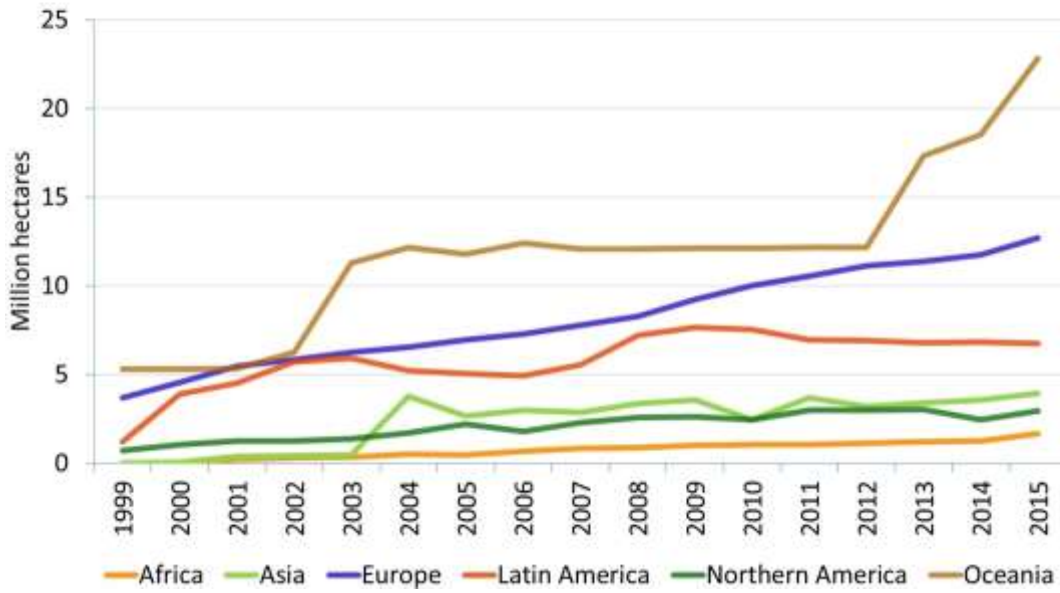

Figure 2. Growth of organic agricultural areas by continent.
Source: FiBL; IFOAM (2017).

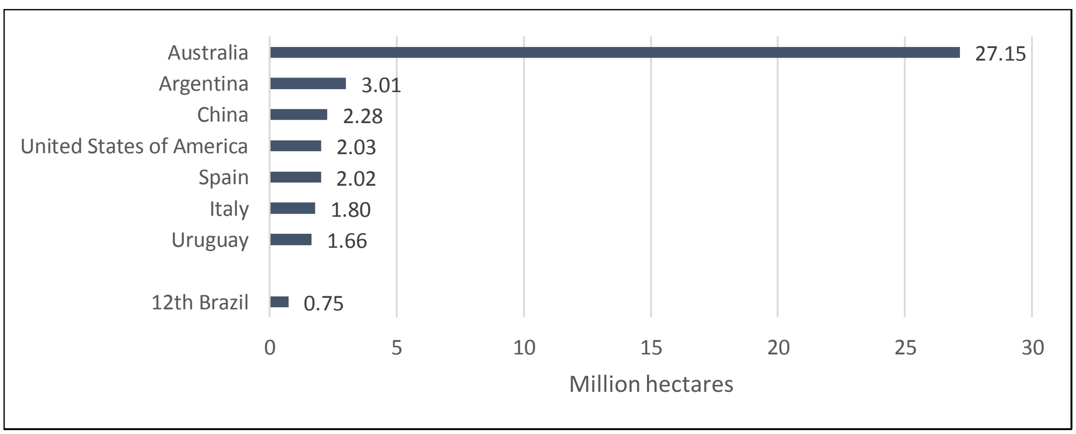

Figure 3. Classification of countries with the largest organic farming areas in 2016.
Source: Adapted from FiBL; IFOAM (2018).

position of 2015. Brazil, in spite of its continental proportions and the fact that a large part of its economy comes from agribusiness, holds only the twelfth place in quantity of lands aimed at organic agriculture, with 750 thousand ha (FiBL; IFOAM, 2018). Still, some statistics evidenced that in the year of 2007 about 32.6 million ha were certified worldwide, of which 6.4 million were located in South America, mainly in Argentina and in the Center-West of Brazil (Fonseca, 2009).

In 2003, Argentina was already the second country, on a global level, with the largest acreage dedicated to organic production. But it was Uruguay – currently with 1.66 million hectares (Figure 3) – that occupied the first position among Latin America's countries, considering its proportion of agricultural lands dedicated to organic farming in relation to conventional farming (Gudynas, 2003). Back then, Mercosul soon became the second trading bloc with the largest organic acreage, lagging behind only the European Union. The main export destinations were the European Union itself, USA and Canada (Gudynas, 2003). Still, for Gudynas (2003), Latin America presented significant growth potential in national and international markets because of its diversity of organic products grown. It is pertinent to emphasize that Latin America has the peculiarity of being a great exporter, which can be intimately associated with the process of colonization of its countries, marked specially by the exploitation of natural resources.

In this sense, Brazil is in the process of consolidating its organic market and the estimate is that it will strengthen in the coming decades. In a research released in the beginning of 2017, the Brazilian Council of Organic and Sustainable Production (ORGANIS) showed that the Brazilian consumer is selective when purchasing and that organic consumption is more restricted to people with higher levels of education and income.

In 2017, Brazil's organic production area remained at approximately 750 thousand hectares. This type of cultivation can be found in 22.5% of Brazilian municipalities according to the Agroecology Coordination (COAGRE) of the Farming and Cooperativism Development Secretariat (SDC). Nevertheless, from 2013 until 2017, Brazil's organic products production more than doubled, highlighting the Southeast region as the largest acreage with 333 thousand hectares and more than 2,700 farmers registered in the National Commission for Agroecology and Organic Production (CNAPO). The second place is the North region, with 158 thousand hectares, followed by the Northeast region with 118.4 thousand, Center-West with 101.8 thousand, and finally, the South region with 37.6 thousand ha (Coagre, 2017). The importance of this growth is in the rural producer's awareness, as they have been decreasing use of chemical inputs in their production, benefiting the consumer, who starts having a healthier product and a more balanced environment. This nationwide advance occurred after the formulation and implementation of public policies by the federal government, such the Food Acquisition Program (PAA) in 2003 and the National School Nutrition Program (PNAE) in 1979, which included organic products in children's school meals. Programs such as these become motivating for the small producer, especially for family farmers, who may have their sales market expanded and not solely dependent on street markets as has occurred in most cases.

ORGANIC MARKET SUPPORT POLICIES

Data from FiBL show that the global organic market traded more than 80 billion euros in 2016 (about US$ 91.2 billion). The United States is the country of greatest individual market for organic food, with approximately 46% of participation in the global market and moving more than US$ 44.4 billion in 2016, followed by Germany (US$ 10.8B), France (US$ 7.6B) and China (US$ 6.7B) (FiBL; IFOAM, 2018).

According to data released by the National Agricultural Statistics Service (NASS) of the United States Agriculture Department (USDA), the gross value of sales of all certified organics produced and sold in the U. S. in 2016 was US$ 7.6 billion. This amount represents a significant increase in these products sales in the country with regard to the year of 2015 (an increase of 23%), and that was because the population had been looking for and preferred to consume organics associated with a real change of habits. There was also increase in production, which made the country reach the mark of more than 14,200 organic production certified farms in 2016 – a total of 2.03 million hectares of lands – which represented an annual increase of 1.5% in production area (USDA, 2017). As to the European Union, implemented in 2014 a regulation that began to regulate production and also boosted organic cultivation. In 2015, the organic market increased by 7% in that region and traded 75 billion of euros (EMBRAPA, 2017). It is worth to highlight Tuson and Lampkin's (2007) contributions, who listed financial policy instruments with emphasis in the commercialization of organic products, such as inspection costs support, which were present in some localities of Germany, Denmark, Luxemburg and Netherlands.

In this context, Kleijn et al. (2001) remind that, in recent decades, the academic community and civil society initiated a discussion on the efficiency of agricultural subsidy programs that aim at preserving biodiversity and promoting environmental sustainability. Authors such as Krebs et al. (1999) and Reganold et al. (2001) emphasized that organic farming subsidy or support programs had as their goal the increase of biodiversity, especially in agricultural pastures. Therefore, studies came up to verify organic farming positive effects as for the initial objective of contributing to biodiversity diversification. For Bengtsson et al. (2005), in most of the cases organic farming brings positive effects to organisms and natural landscapes, among which is biodiversity maintenance. That implies the sector relevance and demonstrates the importance of investments in organic subsidy programs. Howsoever, it is necessary to observe that these programs shall be flexible, adjusting to the particularities of each place where it is implemented.

In the Brazilian scenario, organic farming has been consolidating gradually. The available data shows that there are about 15 thousand properties certified and/or in the process of certification, of which 75% is composed of family agriculturists (Sebrae, 2017). The significant growth in number of organic producing units was evidenced in just three years, going from 6,700, in 2013, to approximately 15,700 units in 2016 (Organicsnet, 2017). The regulation of organic products in Brazil had as a milestone the Law nº 10,831, which established criteria for the production, processing, labelling and marketing of organic products in the country (BRASIL, 2003). However, there is still not a full regulation, in view of the high costs to do so (Santos, 2005). Thus, a more active posture of the state is needed in the process of organic farming regulation, as well as in what concerns commercial policy measures. The small producer, lacking in infrastructure and support (from public or private sectors), will find difficulties in adjusting to organic food

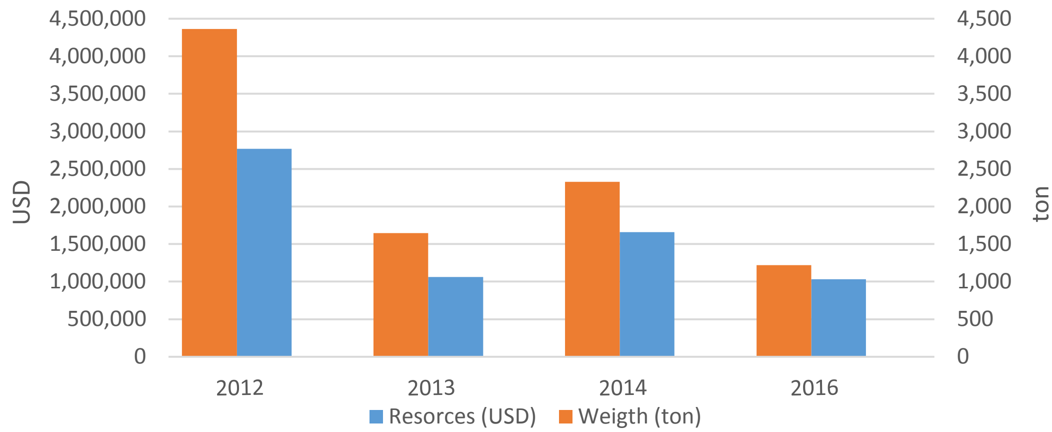

Figure 4. Amount of resources and organic products traded by the Food Acquisition Program (PAA) and the National Supply Company (CONAB) in Brazil.
Source: PAA. Elaboration of the authors. (Currency conversion value: US$ 1 = R$ 3.72).

regulations (Luizzi et al., 2017). This is still a challenge to be conquered that depends on concrete actions of the government.

It is important to emphasize that Brazil's climatic and geographic conditions are quite different from the conditions of developed countries in Europe and North America. Hence, the adjustment to international norms and practices will happen in a distinct way from that which occurs in European countries. This means that Brazilian organic certification peculiarities represent an obstacle to be overcome in the prospect of entering the world market (Ormond et al., 2002).

Another difference is that the internal demand is lower than the external, once the most Brazilian organic products are exported to Europe, the United States and Japan. The Brazilian production of these products is relatively low when compared to developed countries, though the Brazilian organic production growth rate surpasses international rates (Luizzi et al., 2017).

In this context, analysing Brazil's organic products trade is first of all understanding its economic relationship with European, North American and Japanese markets. Moreover, it is relevant to glimpse the organic production system, seeking to make proper use of Brazilian peculiarities such as climate, soil, lands extension, diversity of organically grown produce, among others.

In order to understand the policy to support organic agriculture in Brazil it is necessary to address, in particular, the Food Acquisition Program (PAA). This program is a federal government policy aimed at minimizing hunger and poverty, as well as strengthening family farming. To this end, PAA makes use of trade mechanisms that propitiate the direct acquisition of products coming from family farming or from their organizations. A good part of these acquired foods are intended for school meals, inserted in the context of the National School Nutrition Program (PNAE), which seeks the formation of healthy habits in the educational system (Brasil, 2009; Silva and Souza, 2013), even though challenges related to regularity of production and certification problems persist.

However, in recent years, the amounts operated by PAA intended for Brazil's organic market in Brazil evidencing a considerable drop of more than 60% in total resources invested between 2012 and 2013, as well as in the quantity of products traded in several modalities of PAA (Figure 4). Although there had been an increase of more than 500 thousand dollars for resources in 2014, an investment decrease was again observed in 2016, which recorded the lowest averages for both variables. The modalities and amounts of Brazil's PAA are structured according to the information contained in Table 3. Another form of support from the federal government for the consolidation of organic agriculture was the creation of the so-called "Agro-ecological Records", aimed at meeting the lack of information that farmers has when they decide to enter the organic sector. The initiative stands out as a public policy to encourage the production of organic food, since such records contain techniques of soil management, plant management, techniques of agricultural inputs for sanitary, animal and vegetal control, green fertilization and other practices that assist in organic production. These records are organized and provided by the Ministry of Agriculture and the Organic Production Intelligence Centers (CI Orgânicos) in their respective websites <*www.agricultura.org.br*> and <*www.ciorganicos.com.br*>.

The CI Orgânicos have as their main goal to strengthen organic production in Brazil, using the integration and diffusion of information and knowledge as a tool. It is supported by National SEBRAE (Brazilian Micro and Small Business Support Service) and SEBRAE Rio de Janeiro, and develops a work for the identification, treatment, collection, analysis and dissemination of

Table 3. Modalities of Brazil's PAA (Food Acquisition Program).

Modality	Form of access	Annual Limit	Resource Origin*	Action
Purchase from Family Farming for Simultaneous Donations	Individual	US$ 1,210	MDS	Responsible for the donation of products acquired from family farming to people in situation of food and nutritional insecurity
	Organizations (cooperatives/ associations)	US$ 1,290		
Formation of Stocks by Family Farming –CPR Stock	Organizations (cooperatives/ associations)	US$ 2,150	MDS/ MDA	Makes resources available so that family farming organizations form product stocks for subsequent commercialization.
Direct Purchase from Family Farming – CDAF	Individual or organizations (cooperatives/ associations)	US$ 2,150	MDS/ MDA	Aimed at the acquisition of products with falling prices or according to the need to meet food demands of populations in conditions of food insecurity
Incentive to Milk Production – PAA Milk	Individual or organizations (cooperatives/ associations)	US$ 2,150	MDS	Ensures the free distribution of milk in actions to fight hunger and malnutrition of citizens that are in situation of social vulnerability and/or in state of food and nutritional insecurity. Serves the Northeast states.
Institutional Purchase	Individual or organizations (cooperatives/ associations)	US$ 2,150	-	Purchase aimed at meeting the food consumption regular demands of the Federation, states, the Federal District and municipalities.

*MDS – Ministry of Social Development; MDA – Ministry of Agrarian Development.
Source: Brasil (2017). Ministry of Agrarian Development. (Currency conversion value: US$ 1 = R$ 3.72).

information and strategies for the organic production system development. The result of this work is the increase in quality of products and competitiveness between farmers, benefiting the market and the consumer.

Another tool used by the Ministry of Agriculture are the 578 units of Organic Production Commissions (CPORGs), which have been coordinating actions to stimulate sustainable farming in diverse Brazilian states. From these commissions information exchange between the states' representatives is carried out, as well as the coordination of projects aimed at supporting and generating interest in organic production and increase in the food supply of the country.

Moreover, the National Society of Agriculture (SNA) elaborated a project called *OrganicsNet* (Community Network for the Access of Organic Farmers to the Market) that provides data about the organic market, being a focal point between producers and businesses. This project seeks the improvement of the Brazilian organic production chain through the platform <*www.organicsnet.com.br*>, where the information aim at providing increase of value added to this sector, increase and penetration into the market of small and medium farmers, access to management tools, incentives to the integration and exchange of information, among others. Besides its project on the internet, SNA offers 53 extension courses on organic production chain.

In spite of many efforts to encourage organic farming, there is still a long way to go, considering that Brazil is a country still marked by numerous social inequalities that are mostly caused by the concentration of land in the hands of a few. In this sense, the implementation of more effective public policies becomes necessary and should be thought "from the bottom up", so as to value the small and medium producers who, unlike the large producers of commodities for export, contribute substantially in food production in Brazil.

FINAL CONSIDERATIONS

Countries such as the United States, Germany, France and China lead the organic products commercialization ranking in the global scenario. The production increase curve continues rising and it is estimated that, in a not so distant future, most part of these countries' agricultural production territory will be aimed at organic production. To foster this production, large supermarket chains associated with small farmers have been carrying out the purchase of great quantities of organic food, thus stimulating economy in this sector.

In a desirable way, organic market support policies have been happening in several parts of the world, more significantly in Europe and the United States, motivating organic food producers in cultivation and domestic commercialization matters, and also boosting exports. However, it is necessary to observe that support programs in the sector must be flexible and adjust to local capacities. These aspects are evident when analyzing different countries and continents, each one with its own particularities.

It is worth emphasizing the importance of organic production units in Brazil, which have consistently increased the country's production. The existence of more than 50 companies associated with the Brazilian Council of Organic and Sustainable Production (ORGANIS) and the Organics Project Brazil have boosted both external and domestic markets. On the other hand, public policies, especially the Food Acquisition Program (PAA), which makes use of trading mechanisms that propitiate the direct purchase of products coming from family farming or its organizations, also favor the growth of this production sector in Brazil. In this particular context, the National School Nutrition Program (PNAE) is a highlight, as its products stem from local organic family farming. Nevertheless, as in other countries around the world, challenges related to the regularity of food production and certification still persist.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Review

Integration of tree crops and pastures: Literature review

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Sustainable rural development, integration, and interaction of the livestock, agricultural and forestry components can contribute to reducing the impacts of the productive sector in the environment. In forest environments, plant biomass (mainly of trees) is the main reservoir of mineral nutrients. The forest presence contributes to the elevation of mineral nutrient concentrations in the soil, through leaf deposition. Due to increasing awareness of the importance of environmental preservation and the creation of laws to discipline human action in forests, this paper discusses the integration of tree crops and pastures. In this sense, we discuss the introduction of this model for regional and national cattle production, to expose the weaknesses and the beneficial aspects of the system.

Key words: Cattle production, agroecological system, sustainable development.

INTRODUCTION

In general, human populations value quality food, drinking water, environmental comfort, and leisure, among other aspects. But, they also prioritize the best cost-benefit opportunities in the consumption relation-ships with the productive sector. In response to these assumptions, the rural environment needs to produce to meet the needs of the population for food and other products at competitive costs, but it needs to be done sustainably in time and space, since it is necessary to ensure the maintenance of productive capacity of the future generations (Haile et al., 2008).

In the perspective of sustainable rural development, the integration and interaction of the livestock, agricultural and forestry components can represent a solution for the reduction of the impacts of the productive sector to the environment. This would be possible from the development of a new posture of the agricultural sector, in order to reduce the pressure on natural resources, including forest remnants, allowing the maximum possible biodiversity, the conservationist use of soil and water (Paciullo et al., 2015).

Thus, to maintain productivity, any system must include as many species as possible in the same crop or in succession, maintain high levels of biomass and be as efficient as possible in the use of natural resources. Forest removal represents a drastic reduction in biomass, affecting nutritional balance, energy flow, and consequently the ecosystem sustainability (Garcia el al., 2015).

Agricultural activity, with emphasis on monoculture, has been a factor which accelerates the ecosystems degradation, a serious problem in many countries of the

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world, not only for the opening of natural areas of forests for pasture formation, but also for the management, fire and super-grazing, which contribute to the process of loss of soil structure and gullies (Paciullo et al., 2008). The objective of this article is to discuss the integration of tree crops and pastures.

Research questions

The reviewer developed the following research questions: (1) What are the trends of pasture integration? (2) What are the implications of integrating pasture in the current scenario?

LITERATURE REVIEW

Background and system description

Studies indicate that at least half of the pasture areas in ecologically important regions, such as Amazonia and Central Brazil, would be degraded or degraded (Dias-Filho and Ferreira, 2007). This process is associated with the degradation of soils, water courses and aquatic environments, the loss of biodiversity and the emission of polluting gases (Chará and Murgueitio, 2005). Thus, the recovery of productivity and the conservation of productive areas become a priority due to environmental restrictions that make it unfeasible to incorporate unaltered areas to form new pastures (Dias-Filho and Ferreira, 2007).

In an attempt to reverse the ecosystems environmental degradation, technologies that promote sustainable development with minimum social, economic and environmental costs are sought (Vanzela et al., 2013; Porfírio da Silva, 2015).

The name Agroforestry Systems (SAFs) is given to production systems and technologies that consortiate trees in the production of grains, vegetables and dairy or cutting animals. In these, species are introduced in spatial and temporal arrangements, with the aim of promoting interactions among the components of the system (Coelho, 2012).

This type of production arrangement is also called Plow-Livestock-Forest Integration (ILPF). ILPF is a sustainable production strategy that integrates agricultural, livestock and forestry activities. It consists of the implantation of different productive systems in the same area, in consortium, rotation or succession, through the planting of trees, grains and pastures (Lucas et al., 2015).

This form of land use has two main objectives: productivity, related to the diversification of production and the multiple outputs of the system aiming at income generation, and sustainability, which implies conservation or even improvement of the environmental aspects of the system.

The Silvopastoral System (SSP) is a type of concomitant APS, in which trees live permanently with other small plant species with shorter cycle times and with domestic animals (Coelho, 2012). In these production systems, the intentional combination of trees, pasture and animal component simultaneously occurs in the same area unit and managed in an integrated way, aiming at increasing productivity. This system is also a form of Forest Livestock Integration (ILPF), and has been viewed as an important sustainable land use strategy, especially in areas potentially subject to degradation (Ribaski et al., 2012).

CROP-LIVESTOCK INTEGRATION BENEFITS

The integration of trees into pastures results in several benefits to the components of the ecosystem: climate, soil, microorganisms, forage plants and animals. In traditional systems, an important problem is the burning of pastures (native or cultivated) caused by frost. In an SSP in which pastures are protected between rows of trees, the probability of losses with frost is lower, thus allowing a place with pasture reserve at the critical moments of the year (Lucas et al., 2015).

In the SSP, the trees acquire a complementary or supplementary character of the livestock activity, serving as shade for the herd, helping in the replacement of nutrients of the soil and, as a consequence, improvement of the pasture conditions, being able to serve as forage (Coelho, 2012).

In addition, the use of wood or other products extracted from the forest does not generate income, integrating and increasing the rural property income without the producer having to abandon his traditional vocation for livestock (Ribaski et al., 2012). The introduction of pioneer tree species of multiple use contributes greatly to the success of the system. Among others, they are multiple use species: grandiúva (*Trema micranta* (L.) Blüme Cannabaceae, used in recovery of degraded areas, firewood, cellulose and fodder), bracatinga (*Mimosa scabrella* Bentham, Fabaceae, used in intercropping with yerba mate, lining, flooring and furniture, and for firewood), cambia (*Sesbania virgate* (Cav.) Pers., Fabaceae, used for firewood and honey production, roasted fruits can substitute coffee), ingá-beans (*Inga marginata* Bentham, Fabaceae, used for firewood, honey production, N-fixing and fruits are edible), aroeira-periquita (*Schinus molle* L., Anacardiaceae, wood is used for fence posts and external works, produces industrial oils of high commercial value and the fruits are used for the insecticides production) (Coelho, 2012).

The integration of trees with pastures in the same area can occur through the conservation/maintenance of previously existing trees, by planting trees, or by driving those that emerge naturally in the middle of the pasture. This system allows to intensify the production and, with the integrated management of the natural resources, it avoids its degradation (Porfírio da Silva, 2007; Vanzela et al., 2013).

In this context, agroforestry systems, and in particular SSP, are recommended as a viable option for the recovery of degraded areas, reconciling animal and vegetable production with environmental conservation (Coutinho et al., 2007b; Andrade et al., 2008). Thus, the introduction of the forest component in production systems must take place in an approach that no longer allows for the separation of agriculture, livestock and forest, but rather a real integration of these components in the rural environment, with benefits to the quality of life, sustainability and stability of production (Porfírio da Silva, 2015).

The introduction of trees in pastures, besides other benefits to the environment, provides shade to the animals, avoiding that temperature oscillations decrease the production, because the thermal stress changes their behavior, preventing the animals' grazing in the hot hours of the day. In addition to the radiation, several other climatic factors are influenced by the presence of trees, with reflections on the local microclimate and consequent impacts on the performance of agricultural crops and animal creations. In general, the presence of the forest component provides less variation in temperature and relative humidity, making the environment less vulnerable to climatic extremes (Ribaski et al., 2012).

In SSP, the presence of trees can conserve and / or improve soil quality, favoring erosion control, nutrient cycling and addition of organic matter and capturing nutrients and soil moisture at different depths, thus reducing dependence of external inputs of nutrients or establishing a more positive benefit/cost ratio (Coelho, 2012). Pezarico (2009), concluded that the systems whose organic matter input is higher and uses and management of these environments do not revolve the soil, providing higher soil quality. However, it stresses that the stability is influenced by the adaptation time of the system, so that it promotes the increase of organic matter in quantity and quality, favoring the development of the soil microbial community.

ECO-EFFICIENT APPROACHES TO LAND MANAGEMENT

Planting can be done by planting seeds, or cuttings, depending on the mode of reproduction and growth of the species and the method of forming the system (Vanzela et al., 2013). In this regard, animal's introduction should be careful, especially before the trees reach three years of age or 4 m in height, or when the trees acquire sufficient height so as not to be damaged by the presence of livestock. The entry of animals for grazing inareas without electric fence should be performed only when the trees reach twice the animals height, either cattle or sheep (Lucas, 2015).

In the case of areas with more pronounced relief, the trees should be planted in a level, cutting the terrain slope. In flat areas, you must do the planting in the east-west direction, allowing ample passage of light, which will facilitate the development of grass between the lines (Vanzela et al., 2013). The criteria used in the choice of spacing refer to the ideal spaces for the trees development, because for the pasture development that will be affected by the shading, thinning or thinning of the trees will be carried out in favor of the luminosity required by the forages (Lucas et al., 2015).

Double-line planting consists of an arrangement with two rows of trees planted in close proximity, rather than just one (Vanzela et al., 201 3). The planting method in forests consists of planting small clusters of trees distributed in the pasture. This planting method has two drawbacks.

The first concerns the pasture growth, which is reduced within the forests due to excessive shade. The other concerns nutrient recycling, which is impaired along the pastures, as the animals tend to concentrate more deposition of feces and urine into the woods by spending more time in shaded areas during the day. Over time, there may be a decrease in soil fertility in pasture areas among forests (Vanzela et al., 2013).

This model, however, presents greater potential for timber, due to the greater density of tree plants that make it possible in their arrangement. The consolidation of this potential can take place with the use of adequate spacing and management, in order to guarantee the timber production, the animal's thermal comfort and the pastures development (Nepomuceno and Silva, 2009).

Scattered Planting in Pasture is a form of implantation in which trees can be planted in a random distribution in the pasture, without defined spacing, or may result from the conduction of natural regeneration of trees that arise spontaneously in the pasture. This method is the one that presents the lowest implantation cost among SSP, since it does not require expenses with seedlings or opening of pits and manpower for planting (Porfírio da Silva, 2007). The objectives of this planting arrangement are: soil protection, shading for livestock and improvement of the nutrient cycling provided by the trees, besides obtaining products derived from the trees (wood, oils, resins, etc.) (Vanzela et al., 2013).

Another benefit of this system is that animals receive benefits in the forest habitat. In temperate countries, protection against the cold is an important factor in conserving their energy. In addition, the soil protection by the trees prolongs the period of the pastures palatability in the beginning of the winter, or of the summer in dry climates, besides maintaining in the system the natural biotic and abiotic components and their interrelationships.

FOREST FARMING

For a good result, silvicultural practices must be appropriate and associated with the genetic material of quality to reduce possible negative effects resulting from the SSP (Porfírio da Silva, 2007). Oliveira Neto et al. (2007) commented that the pruning is one of the practices that should be used whenever necessary in the SSP, to reduce the occurrence of nodes in the wood, improving its quality for use in sawmill, and also to favor the availability of light necessary for the good productive performance of pastures occupying the lower stratum.

This practice, however, must be used on the basis of technical criteria, since, depending on the intensity of removal of live branches, as well as the age at which it occurs, there may be a compromise of tree growth and final production. Araújo et al. (2007) found that cattle needs to be handled cautiously in the wet season to avoid damage to the trees root system, with a close and inverse relationship between the intensity of land use and its quality, with the most pronounced quality effects on the soil layer from 0 to 5 cm.

The crowns of the trees contribute to the reduction of the soil erosive process, to reduce the rains impact, besides serving as windbreaks. On the other hand, their root system, which is generally dense and deep, forms barriers preventing soil particles from dragging, as well as, it can absorb nutrients from the deeper layers by translocating them to the leaves. After the fall, the leaves deposition and decomposition, these become excellent sources of organic fertilization, improving the physical and chemical characteristics of the soil. In drought periods, soils have a higher moisture content under their canopy than in areas exposed directly to the sun and wind, contributing to improve the quantitative and qualitative performance of forage grasses (Vanzela et al., 2013).

From an environmental and productive perspective, one of the main advantages of SSP is to carry out the proposal of multiple use of the land by increasing the efficiency of resource use on a spatial and temporal scale, reducing risks, increasing systems stability, and to promote the social and recreational use of land, as quoted in the Silvopastoral Declaration (Mosquera-Losada et al., 2006).

Nepomuceno and Silva (2009) observed associations of eucalyptus (*Eucalyptus* species, Myrtaceae) and grevílea (*Grevillea robusta* Cunn., Proteaceae) with native species such as the canafístula (*Peltophorum dubium* (Spreng.) Taub., Fabaceae), gurucaia or angico-red *(Parapiptadenia rigida* (Benth) Brenan, Fabaceae), guabiroba (*Campomanesia guaviroba* (DC) Kiaersk., Myrtaceae), aroeira and yellow-ipê; the authors did not mention the species of aroeira or ipê-amarillo, being in question *Schinus terebintifolius* Raddi and *Myracroduom urundeuva* Fr. (aroeiras, Anacardiaceae) and *Handroanthus chrysotrichus* (Mart.) Mattos, *Hemicentrotus pulcherrimus (Sanduith.) SOGrose* and *Polyporus umbellatus* (Sond.) Mattos (*yellow-ipês,* Bignoniaceae).

Most SSPs carried out in Brazil are composed of Eucalyptus species L' Hér., and a good part of the recent studies are concentrated in the Southeast region of the country, where species of this genus have been cultivated mainly for the production of firewood in cycles of short rotation (Paciullo et al., 2007b; Nepomuceno and Silva, 2009). The preference for eucalyptus is associated with the possibility of obtaining several products, their high growth rate and ease of regrowth, and variations in crown density, which facilitates the availability of incident solar radiation in the understory, making it feasible to establish of the herbaceous forage species and, consequently, the SSP sustainability (Oliveira Neto et al., 2007; Oliveira et al., 2007a, b).

The system using eucalyptus tends to have problems with nitrogen (N) immobilization in the soil, due to the high deposited C/N ratio, which favors the competition between grasses and eucalyptus and the reduction of the amount of N available to the forage (Carvalho and Pires, 2008). In this case, studies have indicated that the association of legumes to eucalyptus plantation may represent future gains in terms of fertility, synchronism to the nutritional demand of eucalyptus and relevance due to N also required for herbaceous forage species, particularly grasses and studies have been performed, in order to evaluate the behavior of different species in SSPs (Dias et al., 2007a).

Thus, when planning a SSP based on eucalyptus, it is important to consider alternatives to minimize possible negative interactions between the pasture and the trees (Paciullo et al., 2007b). Annual application of nitrogen fertilizers increases the dry matter yield of forages, however, the response to fertilization is directly related to the degree of shading, because the greater the shading, the less the response of grasses to fertilization.

One of the requirements for the success of sustainable SSPs is due to the species selection to compose these systems. Concerning the trees, the diversity of species directly influences the system stability (Pezarico, 2009).

The choice of forage species is important in an SSP. One can opt for a system with exclusively cultivated forages or an improvement of the native field. The improvement of native pastures by introducing cultured species should be done by direct seeding over sowing or without the use of desiccants (Lucas et al., 2015). Grasses of the genus *Paspalum* and *Panicum* have flexibility of use because they have satisfactory production potential, regrowth vigor, satisfactory nutritional value, tolerance to shading, besides being adapted to the most varied climate and soil conditions. Thus, they become important as forage species to be used in SSPs (Alvim et al., 1996).

The species of the genus *Brachiaria* (Trin.) Griseb., has also been shown to be quite tolerant to shading, responding structurally to environmental changes, without loss of productivity and forage quality (Martins et al., 2009). *Mimosa tenuiflora* (Wild.) Poir is a species indicated to be introduced successfully in the pastures of

Brachiaria decumbens Stapf. Prain., without the protection of their seedlings and in the presence of cattle (Dias et al., 2007b).

In systems where livestock production is integrated with the forest, grazing can be implemented before or after tree planting. Preferably, pasture must be implanted before the tree component, which allows a greater ease of mechanized operations in the area and anticipation of the use of forages.

Grazing in the initial stage of tree development is possible, provided that initiatives are taken to prevent animal damage to them. Thus, in the first year of establishment, an electric fence can be used to keep animals grazing at a safe distance from the plants, but it is important that the animals are accustomed to handling this type of fence, which can be obtained if the animals experience previous electrical shock in other areas of the property (Menarim et al., 2009).

Another alternative is the exclusive use of the area for the production of hay or silage in the first years, while the seedlings do not reach the ideal size for the integration with the animals, or to keep the pastures without grazing so that they can produce seeds, to ensure the natural reseeding of the species and maintain the system productive potential in subsequent years (Lucas et al., 2015).

For species that have a good natural resemblance, it is important that in the reproductive stage of the species (from the flowering), a reduction of the animal load or even the fallow of the area is carried out, so that the species can produce seeds in good quantity and quality and restore pasture in the next productive cycle. Likewise, it is important to consider the characteristics of each forage species, such as growth habit, flowering season and forage cycle.

In addition to the benefits of SSP adoption, a number of studies have been carried out, especially those aimed at improving the physical, chemical and biological quality of the soil (Tripathi et al., 2005; Lok, 2006; Nair et al., 2007). In the present study, it is possible to evaluate the quality of the pasture (Paula et al., 2007a, 2008), animal comfort and, more recently, the environmental services provided by these systems and other factors that contribute to the disease development. The use of tree and shrub species in SSP for the purpose of forage production has also been the subject of studies in Brazil (Silva et al., 2007; Dias et al., 2007b; Paciullo et al., 2007a) and abroad (Shelton et al., 2005; Ainalis et al., 2006).

It is possible to take advantage of the initial growth stage of the tree component for an adequate implantation of forage species, especially focusing on the establishment of species of slow initial development, such as perennial winter legumes (Lucas et al., 2015).

POTENTIAL HABITAT AND BIODIVERSITY LOSSES

From a technical point of view, the benefits of SSPs represent a long-term strategic interest for environmental conservation, for producers, afforestation of pastures should present a real benefit in the short and medium term. According to Porfírio da Silva (2007), the producer's main objectives when associating trees with pasture are: (a) to increase the total income of pasture lands; (b) increase the role of what to produce and, thus, reduce economic risks; c) preserve their way of life and their survival while conserving resources (Radomski and Ribaski, 2012).

Regarding grazing management, it is important to always observe the height of the forage plants before entering and during the animals' grazing (Carvalho, 1998). Due to the light restriction because of the presence of trees, a conservative management is recommended, and it is essential to adjust the animal load in order to maintain pasture with a minimum residue height between 15 and 20 cm (Lucas et al., 2015).

In a SSP, the amount of available light is one of the main factors that determines the growth and production of forages, and is conditioned basically to the management of four variables (Varella et al., 2008): (a) spacing, by density tree planting arrangement; (b) selection of species with not very dense crown; (c) thinning and pruning of trees; (d) shading tolerant forages.

CONCLUSIONS

Productive systems that include the combination of tree fodder can contribute to increased management efficiency and use of natural resources, as well as to the sustainability of rural properties, especially small ones. This avoids environmental degradation and improves the quality of life of rural producers by increasing pasture productivity, gaining livestock and harvesting forest products, and diversifying income in rural properties.

The SSP is a strategy to optimize the existing differential in regional and national cattle breeding: herds in pasture. With this, it can help to consolidate Brazilian cattle breeding as environmentally adequate in the world scenario.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Review

Yam (*Dioscorea* spp.) production trends in Cameroon: A review

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Yam (*Dioscorea* spp.) cultivation has the potentials to greatly contribute to poverty alleviation and food security, in Cameroon. The full production potentials of yams have not been exploited, leaving Cameroon with an annual production of 648,407 metric tons (MT) at the sixth position, among the six countries of the West African yam zone, with 67.3 million MT. This review highlights research gaps in the yam production chain, which can be exploited to enhance production in the country. Subsistent yam cultivation takes place in all five agro-ecological zones of the country. Although with many fluctuations, yield and production quantities have recorded a marginal net increase, since 1961. Cameroon has nine cultivated and 17 wild species, exploited by Baka pigmies for food, but there is no established genebank, thereby exposing the genotypes to genetic erosion. Cultivated species are both indigenous and exotic, and traditional seed systems (sorting, junking, and milking) are exploited for seed procurement. Minisett technology is also gaining grounds. Yam processing is very limited, and, coupled with poor conservation facilities, contributes to elevated post-harvest losses. The yam marketing system is poorly organized, and hinders farmers from reaping optimum benefit from the activity. Other major constraints to yam production include high labour demand, pests and diseases, absence of improved seeds and research neglect. There is the need for concerted efforts involving all stake holders in the yam production chain to enhance yam production in Cameroon.

Key words: Review, yam (*Dioscorea* spp.), production, Cameroon.

INTRODUCTION

Yam is an annual or perennial tuber-producing vine, belonging to the genus *Dioscorea* (family Dioscoreaceae) with about 600 species (Alexander and Coursey, 1969; Oben et al., 2016).The crop is an important staple for hundreds of millions of people in tropical and subtropical areas of Africa, Asia, South America, and the Caribbean

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and Pacific Islands (Degras, 1993; Ngo-Ngwe et al., 2014). Yam is most important in the “yam zone” of West Africa which covers the tropical and subtropical regions of Côte d’Ivoire, Ghana, Togo, Benin, Nigeria and Cameroon (Oben et al., 2016) where over 67.3 million metric tons (MT) (92.2%) of the world’s estimated 73 million metric tons (MT) of yams are produced yearly (FAO, 2017). Nigeria stands out as the highest producer with 47.9 million MT (65.7%) of the world’s production, while Cameroon with an annual production of 648,407 MT (0.9%), is ranked sixth in the West African yam zone and seventh in the world, behind Togo. On an annual base, yams are cultivated in Cameroon on a surface area of 57512 ha; with an average yield of 11.3 MT/ha (FAO, 2017).

Globally, there are 10 main cultivated yam species, originating from tropical areas of Africa, South East Asia and South America. These include *D. alata* L (Asiatic or water yam), *D. esculenta* (Lour) (Chinese yam), *D. opposite* Thunb, and *D. japonica* Thunb from Asia; *D. nummularia* Lam, *D. pentaphylla* L. from Asia and Oceania; *D. rotundata* Poir (White guinea yam), *D. dumetorum* (Kunth) Pax (Sweet yam) and *D. cayenensis* Lam (Yellow guinea yam) from West Africa; *D. trifida* L. (Cush-cush yam) from South America; and *D. bulbifera* L. from Africa and Asia (Coursey, 1976; Lyonga, 1976; Dansi et al*.,* 2013). Water yam is the most diversified and widely distributed species while White guinea yam has the world’s highest production level. Among the yam species, *D. alata, D. cayenensis and D. rotundata* are most economically important in the west African yam zone (Dansi et al*.,* 2013), while in Cameroon *D. alata, D. cayenensis, D. dumetorum, D. rotundata* are the most important species, cultivated in all agro - ecological zones of the country (Ngo-Ngwe et al*.,* 2014).

Yam is an important food plant because of its underground tubers and/or aerial bulbils, which are a good source of carbohydrates, proteins and vitamins, particularly vitamin C (Bell, 1983; Agbor-Egbe and Treche, 1995). In addition, yam and its products are reported to have a low glycemic index, which gives better protection against diabetes and obesity (Siadjeu et al*.,* 2015). Yam production is also a major income generating activity for the people of yam-growing areas (Acquah and Evange, 1994; Leng et al., 2016) and thus provides other opportunities for poverty alleviation and nourishment. Some species, particularly *D. zingiberensis,* which contain high concentrations of diosgenin, are used to produce contraceptive pills and sex hormones (Coursey, 1967). The crop also has socio-cultural importance and is an elitist food crop of choice in Cameroon.

Despite its importance, yam production and productivity have been limited by a range of constraints including unavailability and high cost of seed yams, high demands of labour, pre- and post-harvest pests, inadequate storage facilities, various diseases and institutional research neglect of the crop. Although yam has been cultivated in Cameroon for at least two centuries, research on the crop has generally been scanty compared with the rest of the countries of the African yam zone. The previous research on yam in Cameroon has been carried out in isolation and without any coordinated effort. The overall objective of this review paper is to compile available literature on yam and seed yam production in Cameroon, to highlight gaps on yam research in the country, with the aim of attracting the attention of researchers and donors to invest in enhancing yam production with potential spill over to neighboring countries in central Africa.

YAM PRODUCTION IN CAMEROON

Major yam growing areas

Cameroon is located in the Gulf of Guinea, between latitude 1.7° N to 13.8° N, and longitude 8.4°E to 16.8°E and covers a surface area of 475,440 km^2. It shares common borders with Nigeria, Chad, Central African Republic, Gabon and Equatorial Guinea. The country is characterized by a wide variety of climatic zones and vegetations; tropical forest and swamp in the South, savannah landscapes in the North and altitude pastures on the Western Highlands (Yengoh and Ardö, 2014). Cameroon is made up of 10 administrative regions found in five main agro-ecological zones as detailed in Table 1 (Toukam et al*.,* 2009).

Subsistent yam cultivation is carried out in all the five agro-ecological zones, but major yam-growing areas are found in Zone II, III, IV and V, mostly in Adamawa, Southwest, Littoral, Northwest, West, East and Centre Regions. However, high levels of yam production have been reported in the North Region precisely in Mayo-Rey and Faro (Ngue-Bissa et al*.,* 2007). Adamawa Region (Mbe plain) is the highest producer followed by Southwest, Littoral, Centre, West, East and Northwest Regions (Ngassam et al*.,* 2007). Cameroon’s climate and soils, like other countries of the “yam zone” of West Africa are favourable for high level cultivation of yams and other root and tuber crops. However, yam diversity within regions is still very limited. Diversification and improved yam cultivation to meet growing demands of the galloping urban population need enhanced commitment of yam researchers and donors.

Yam production trend in Cameroon: 1961- 2017

In Cameroon, yam production has witnessed a lot of fluctuations but has more or less stagnated below an annual production of 650,000 MT, since1961 with a few peak periods in 1972/73 and 2017 (Figure 1). After the reunification of Cameroons in 1961, there was a cut in

Table 1. Main characteristics of agro-ecological zones of Cameroon.

Agro-ecological zones (constituent regions)	Annual rainfall (mm)	Elevation (masl)	Mean annual temp. (°C) (range)
Zone I: Sudano-sahelian (North and Far North)	500-900	250 - 500	28 (±7.7)
Zone II: High guinea savannah (Adamawa)	1500-1800	500 - 1500	23(±6.4)
Zone III: Western highland (West and Northwest)	1800-2400	1500 - 2500	21 (±2.2)
Zone IV: Humid forest with monomodal rainfall (Southwest and Littoral)	2000-11000	0 - 2500	26 (±2.8)
Zone V: Humid forest with bimodal rainfall (Centre, South and East)	1500-2000	400 - 1000	25 (±2.4)

masl= meters above sea level; *Source:* Toukam et al. (2009).

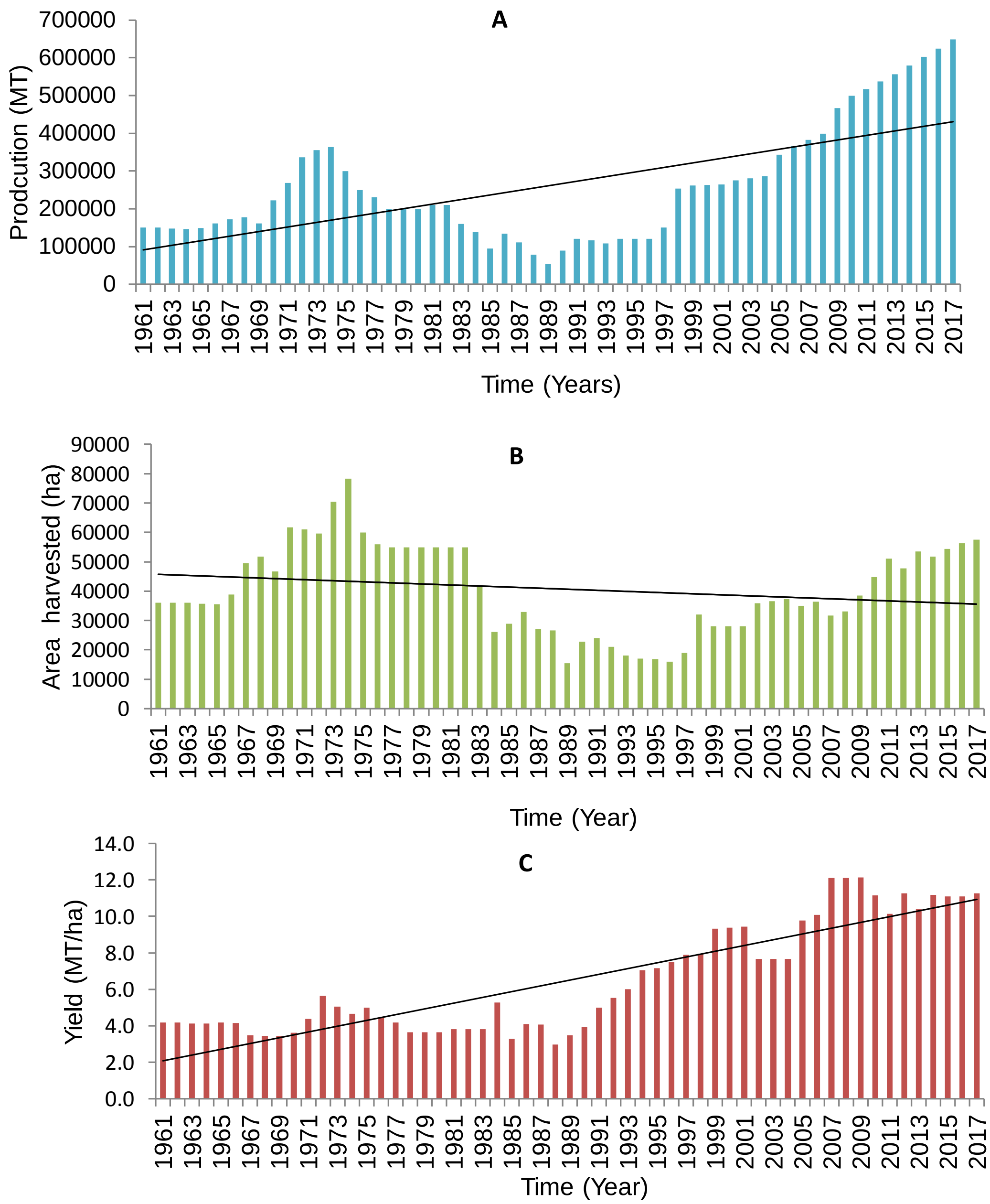

Figure 1. Variation of yam; (A) production quantities (MT); (B) area harvested (ha), and (C) yield (MT/ha) in Cameroon from 1961 to 2017.
Source: FAOSTAT (2017)

the import of white yam from the former Eastern Nigeria, due to the West Cameroon government's concern with the loss of currency to Nigeria through importation of this commodity. This led to a drastic decrease in the supply of yams in Cameroon, to meet high demand in the country. Efforts to increase yam production led to the formation of the West Cameroon yam scheme in 1963 (Lyonga and Ayuk-Takem, 1982), with the duty to develop new yam varieties and to set a practical framework to reduce yam importation from Nigeria (Ngeve, 1998). Through this scheme, the government promoted yam production by demonstrating the importance of yam cultivation to farmers, training them on yam husbandry and supplying them with subsidized seed yams (over 167,000 seeds of 'Ogoja' yams) from Nigeria, which later became too expensive to import. Attention was turned to the then Central South Province of the country where the 'Mban' cultivar of *D. rotundata*, (characterized by smaller tuber size and low yield), was a substitute, especially in the hot lowlands. This government effort led to a large increase in yam production (215,000 to 380,000 MT) between 1969 and 1973 (Figure 1). Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres (IRAT) in charge of food crop research at the time later included yam research in its program. However, yam cultivation was and is still left in the hands of peasant farmers, who lack inputs and adequate knowledge in yam cultivation, to meet growing demands. Yam production as a result, dropped steadily from 1973 to 1989, followed by another rising phase to present time, 2018 (Figure 1).

Yam cultivation in the Mbe plain entered into crisis within the 1973 to 1989 period, as a result of lack of material and an unfavourable production calendar. Following the creation of the cotton producing company (SODECOTON) in 1974 and extension of its activities along the Garoua – Ngaoundere road axis, many youths within the plain developed lack of interest in yam cultivation, in favour of cotton farming, attracted by better offers such as; access to loans, farm inputs and mechanized farming from the company (Seignobos, 1998). Furthermore, due to the almost total dependence on a single yam cultivar (*Bakokae*) at the time, and lack of means to conserve tubers in the first harvest (weaning), the economic activity, based on yams sales, was restricted to the period between mid-July and February/march, leaving a gap in October and November. This helped to discouraged yam cultivation in the zone.

The net, although slow increase in yam production after 1989, might probably be due to the introduction and adoption of minisett technology in the country's seed system through the National Agricultural Extension and Research Program (PNVRA) in the early 1980s. This was jointly carried out by Cameroon's ministry of agriculture, Institute of Research for Agricultural Development (IRAD), Universities-particularly the "Faculté d'Agronomie et des Sciences Agricoles (FASA)"of the University of Dschang, in collaboration with IITA. The program was funded by African Development Bank (ADB), Cameroon government, World Bank, and International Fund for Agricultural Development (IFAD) (Nchinda et al*.,* 2010). For proper coordination of research to meet the needs of the entire country, the national program for roots and tubers development (NPRTD) was created in 1997, with the goal to develop improved varieties of cassava, cocoyam, taro, yams, sweet potatoes and Irish potatoes. Through the program more yam farmers were trained on seed yam production through minsett technology (Ngue-Bissa et al*.,* 2007). However, in comparative terms, this increase in yam production is consistently far lower than in the other countries of the West African yam zone, with a last rank of sixth amongst the six countries of the zone. Lyonga (1976) and Ngue-Bissa et al*.* (2007), projected 1,324,000 and 722,509 MT of yam production in 1980/81 and 2002/2003, respectively, but these projections are far higher than FAO yam production estimates for this same periods.

Area harvested has remained stagnant below 80,000 ha, with a slight overall decline since 1961, nevertheless production has continued to increase, although slowly, between 1990 and 2017 (Figure 1), with a concomitant and progressive yield increase as well (Figure 1; FAO, 2017). This indicates that yam production is not expanding in terms of surface area cultivated, but farmers involved in the yam sector might have gained more experience in yam production procedures and need more encouragement through research to enhance yam production. In 2006, the national yield estimate for yam in Cameroon stood at 6.08 MT/ha (Nchinda et al*.,* 2010), accounting for about 50% of the African average yield of 11 MT/ha. However, according to the food and agricultural organization statistics for the same year, Cameroon recorded a yield of 10.1MT/ha. Among the main yam-growing regions, the best yields (11.13 MT/ha) have been recorded in Adamawa. However, in Zone III (Western highlands), annual yields as low as 3.08 MT/ha have been recorded (Ngue-Bissa et al*.,* 2007). Enhanced holistic research on yams will therefore better promote yam production in the country, in a manner similar to attention given to other root and tuber crops such as cassava and taro which have seen greater investment in research, especially improved varieties, which is credited with the production increase of those crops (Ngassam et al*.,* 2007; Njukwe et al., 2014).

YAM CULTIVATION

Growing season

The yam growing season in Cameroon varies with agro-ecological zones, but throughout the country the planting season extends from November to May with harvesting 6 to 10 months later, depending on the species and variety. Acquah and Evange (1991) reported that the growing season also varies within the agro-ecological zone. In

Table 2. Effects of planting date on the yield of *Oshie* white yam (*D. rotundata*) in the high altitude savannah of Cameroon.

Planting date	Part of tuber used for seed and yield (MT/ha)	
	Terminal	Basal
December	31.0	25.8
February	26.1	21.7
March	18.5	15.4
April	7.6	6.4
May	5.6	4.7

Source: Adapted from Ngeve (1998).

Buea (Bonakanda), a major yam-growing area in agro-ecological zone IV (Southwest Region), planting extends from November to February and first (ware yam) harvest takes place from May to July, while the second (seed and ware yam) harvest takes place from August to October. In Malende within the same agro-ecological zone, planting goes from February to May and harvesting extends from November to April. Seignobos (1998) reported that in the northern parts of the country particularly at Mbe plain in Adamawa, planting starts from mid-March to the start of June and ware yam harvest from September to January. The same study indicates that the variety of *D. rotundata* called *Bakokae,* commonly cultivated in the zone is planted in April and May, and harvest starts in September while the early-maturing variety called *Ngang* is planted in April and harvested by mid-July. In the high altitude savannah, the yield of *Oshie* white yam (a variety of *D. rotundata*) reduced by 16, 40, 75 and 82%, if instead of December, planting is carried out in February, March, April and May (Table 2). Furthermore, the terminal parts of the tubers used as seeds produce better than the basal parts (Ngeve, 1998). This indicates that planting in December, before the arrival of rains, is favourable for yam production within this zone, and generally emphasizes the importance of proper timing of the planting date in yam cultivation. Information related to the yam-growing season is lacking, for other yam species and yam-growing agro-ecological zones.

Seed yam sources

Local yam varieties are inherited and cultivated as part of the culture in many areas of the country. This is the case with varieties of *D. rotundata* called *Bakokae* and *Ngang* which are intensively cultivated in the Mbe plain of Adamawa (Seignobos, 1998). Also, local varieties of *D. dumetorum* (in most parts of the country), *D. alata* and *D. rotundata* (Mban cultivar) in the Centre and South Regions, and *D. cayenensis* in the West and Northwest Regions have probably been domesticated and cultivated as part of the people's culture. Many exotic species and varieties have also been imported from Guadeloupe – West Indies (cultivars of *D. alata, D. trifida*), Nigeria (many cultivars of *D. rotundata, D. alata* "Ogoja" and *D. cayenensis*) (Lyonga, 1976) and Côte d'Ivoire (*D. alata* cv. "Florido"). Seed yams of both exotic and local varieties are maintained through many traditional seed propagation techniques such as milking/weaning. In yam varieties with double harvest, the first harvest called milking produces ware yams which are generally larger in size, physiological immature and more fragile to conserve (Dumont, 1998). The second harvest generally produces smaller and physiologically mature tubers which mostly serve as planting material. Although scarce, seed yams are also bought from local markets. Seedling and foodstuff development authority (MIDEVIV) in the 1980s and NPRTD, have produced and distributed seed yams to farmers in the country (Nchinda et al*.,* 2010).

Despite these efforts, lack of improved clean seed yams remain a major constraint to yam production (Acquah and Evange, 1994). In addition to its high cost, accounting for about 323,680CFA (US $560) (40%) of production cost per hectare, seed yams are very scarce and improved varieties are lacking in Cameroon. Furthermore, the fact that yam is mostly propagated vegetatively, using tubers which are equally used as food, greatly contributes to seed yam scarcity. Smallholder farmers, who produce most of the yams in Cameroon, also consume their own seed yams during periods of food shortages, leading to severe shortages of planting material for the next season. There is therefore an urgent need to develop and adopt alternative seed yam propagation techniques, to improve clean seed yam availability and subsequent yam production capacity in Cameroon.

Weight of seed yams

Since yam production in Cameroon is carried out mostly by smallholder farmers, the exact seed yam weight is not an important consideration to them, as they only estimate the size of their setts. All other aspects being at their optimum, the size of tubers produced is directly related to the size of setts used. Lyonga (1976) reported that 125 g yam setts are best for seed yam production while 375 to 500 g are best for ware yam production. Seignobos (1998) reported that for the yam cultivar called *Bakokae* the Dourou people of Adamawa use seed yam size of about 12 cm, mostly weighing between 250 and 400 g but could attain 625 g. The earlier the planting date, the larger the sett size required, to resist irregular rains at the start of the planting season.

Seed yam propagation

Both innovative and traditional methods are employed in Cameroon for seed yam production. These include seeds obtained from milking/weaning/tapping, small ware tuber sett cuttings, seed yam from minisett technology (Ngeve and Nolte, 2001; Ngue-Bissa et al*.,* 2007; Nchinda et al*.,* 2010). Milking/weaning, is the most popular traditional method for seed yam production. Seignobos (1998), reported that to sustain cultivation of *Bakokae* and *Ngang* (Cultivars of *D. rotundata*) at the Mbe plain, this technique is commonly used by farmers as a means of producing planting material for the next planting season. The technique consists of carefully digging, cutting around the collar and removing the main yam tuber without damaging roots at about five to six months after planting. The remaining part of the stem is properly covered with soil and allowed to produce smaller adventitious tubers, which are harvested after about three months to serve as seeds. Sorting is another traditional method, in which small seed sized tubers from species that produce both ware and seed sized tubers, are sorted and used as seed yams (Figure 2), while larger ones are eaten or sold. This technique has the risk of selecting and using infected small tubers. Large ware tubers are sometimes cut into seed sized setts and used as seed yams (Ngue-Bissa et al*.,* 2007), a technique called "junking" (Figure 2; Aighewi et al*.,* 2014).

Innovative yam seed propagation techniques include minisett technology which is gradually being adopted by yam farmers in parts of the country. Through the National Root and Tuber Development Program (NPRTD), the International Institute of Tropical Agriculture (IITA), and Institute of Agricultural Research for Development (IRAD), many yam farmers have been trained on the technique (Ngue-Bissa and Mbiaranodji, 2007). Unfortunately, no assessment has probably been done to improve on this outreach strategy (Nchinda et al*.,* 2010). Some farmers, particularly in the Southwest Region, now consider the technique profitable and have embraced it. Other methods of seed yam propagation such as vine rooting, tissue culture, aeroponics, temporary immersion bioreactor technology, somatic embryogenesis (Mignouna et al*.,* 2016), have not been adopted in Cameroon.

Yam cultivation methods

Land preparation

Yam cultivation practices in Cameroon vary from region to region. In general, yam farmers in the country prefer long fallowed land or newly opened land for yam cultivation since yam requires high soil fertility. All starts with land preparation, which generally involves manual clearing and tilling of the soil into mounds, ridges, or flat beds. Pfeiffer and Lyonga (1987) reported that the preparation of ridges takes about 35 to 40% of the working time used in yam cultivation. A few commercial farmers use tractors but most employ manual labour for this purpose. Lyonga (1976) reported that growing yams on ridges or mounds does not have any significant effect on the yield of *Oshie* white yams (Table 3). However, flat beds affect the shape of tubers and increase tissue damage due to exposure to the heat of the sun. On the contrary, Seignobos (1998) reported that at Mbe plain in Adamawa, planting on flat beds reduces the yield of *Bakokae* and *Ngang* by 30 to 35% compared to ridges. This stresses the need to determine and implement adapted planting methods that can promote yield in all the yam-growing zones.

Planting

Land preparation is followed by planting and mulching with grass during dry periods, to limit desiccation. There is no precise plant density per hectare, as farmers mostly estimate the quantity of plants in their farms, in terms of the number of ridges or estimated farm sizes. Lyonga (1976), reported that there is no significant difference in yield of *Oshie* white yam when planted at a density of 20,000 and 15,000 stands/ha (Table 3). The yield in both cases is significantly higher, compared with a plant density of 15,000 and 5,000 stands/ha (Table 3). However, average tuber yield decreases with increased plant density. Except at Mbe plain, where "Dourou" people practice mono-cropping of yams (Figure 2), farmers in the rest of the main yam-growing areas, particularly in the Western highland and forest zones, intercrop yams with maize, cocoyam, cassava, coffee, groundnuts and many other food crops (Figure 2) (Lyonga, 1976; Ngeve, 1998). This is mostly for food security, since yam is not a staple food crop, but more or less a cash crop in the country. However, reports indicate that, intercropping of *D. rotundata* with maize significantly reduces yield by as much as 57.3% (Ngeve, 1998).

Improvement of soils fertility

Although yams, especially white guinea yam (*D. rotundata*), are very demanding in soil fertility, Lyonga (1976) reported that the application of inorganic fertilizer

Figure 2. Some traditional seed yam systems, cropping patterns and ware yams marketing locations in Cameroon: (A) Small tubers selected for setts (Sorting); (B) 200-250g setts sliced from large tubers (junking), (C) section of a monocropped farm (D) yams intercropped with cocoyam, (E) section of a road side market at Mbe (Ngaoundere – Garoua highway), Adamawa Region (F) section of the terminal market at Bamenda, Northwest Region.

does not significantly improve the yield of the variety called *Oshie* white yam (Table 3). However, other studies indicate that in the Western highland the same cultivar (*Oshie* white yam), produced better yields in the presence of inorganic (especially nitrogenous) fertilizer (Ngeve, 1998). Vernier (1998) reported that the application of inorganic fertilizer negatively affects the organoleptic properties of yam tubers, and also renders them more susceptible to post-harvest pests and diseases. Besides, many farmers cannot afford these fertilizers due to high prizes. This indicates the necessity to evaluate and adopt cheaper alternatives, particularly organic fertilizers, to enhance yam production.

Field management

For weeds and pest management, a few farmers treat their seed yams with insecticides of varying names, to destroy insect pests and apply herbicides such as "Roundup" to reduce weeds. Most farmers do manual weeding and many do not treat their seed yams before

Table 3. Effects of seed-bed preparation, fertilizer application and plant density on the yield of *Oshie* yam in Cameroon.

Effect of plant pattern	Flat beds	Ridges
Total yield (MT/ha)	17.62[a]	15.70[a]
Good tuber yield (MT/ha)	15.93[a]	15.67[a]
Net loss (%)	6.4	0.19
Fertilizer application		
Fertilized	16.97a	16.16[a]
Non-fertilized	17.03a	15.30[a]
Effects of plant density (stands/ha)		
20,000	21.92[a]	
15,000	19.92[a]	
15,000	14.51[b]	
5,000	9.16[c]	

Values with different letters attached are significantly different at p=0.05 (DMRT).
Source: Lyonga (1976).

planting. Many farmers use wooden stakes to support the vines for adequate exposure to sunlight while others do not consider the practice important. Shorter stakes are preferable in the North while taller ones are preferable in the Southern part of the country (Lyonga and Ayuk-Takem, 1982). Ngeve (1998), reported that staking is not absolutely necessary for *D. dumetorum*, but for *D. rotundata* and *D. cayenensis,* providing a yield increase of 52 and 39%, respectively. The same information does not exist for other yam species and cultivars. In their quest for stakes, farmers cut down small trees which gradually become scarce and protected. Alternative staking material needs to be adopted, to save the forest.

Exploitation of wild yams by Baka pigmies

Baka pigmies of East and South-East Cameroon, carry out a form of yam cultivation called "paracultivation" on wild edible yams (Dounias, 2001). "Paracultivation" is a combination of technical patterns and social rules which structure the exploitation of wild yams. In paracultivation, a specific technical process is involved in harvesting vertical elongated tubers of paracultivated wild yams such as *D. praehensilis* and *D. semperflorens*. In the technique, the soil bordering the tuber is carefully excavated using a special auger or sharpened stick and the tubers are removed for food, making sure to preserve a portion of the tuber with the head, and to leave the terminal part of the tuber. The pit is then back-filled with a mixture of earth and humus. The refilled soil is enriched with organic matter and is less compacted than the original soil, so that new tubers encounter less mechanical resistance, during their growth and development. As such, paracultivation promotes increase tubers within each yam pit (Dounias, 2001). Paracultivation aims at encouraging production, so that the plant can be repeatedly exploited, and voluntarily maintained within its natural environment, in order to better respond to the seasonal mobility of these forest dwellers. This maintenance of plants in the forest is the key difference between paracultivation and proto-farming and is a step to yam domestication.

Several social rules which code wild yam exploitation by Baka pigmies include: Exclusive rights of ownership with possible inheritance of managed plants, ritual protection, and specific treatment which the resource receives, such as food (prestige dishes, components of bride wealth) (Dounias, 2001).

YAM CONSUMPTION AND OTHER USES

As in all countries of inter-tropical areas of the world, yam contributes immensely to food security, and has socio-cultural as well as medicinal values. Yam is consumed in various forms; mostly boiled and eaten with soup, and pounded yam (fufu), roasted, baked, or fritters in wheat flower, and as chips (Agbor-Egbe and Treche, 1995; Leng et al., 2016). It is sometime made into flour and mixed with sugar and milk particularly for consumption by children. Yam processing and transformation remain very limited, which contributes to elevated post-harvest losses. Generally, yam is not considered a staple food crop in Cameroon even among yam farmers, who consider it more, as a cash crop. This is the case with the "Dourou" people of Adamawa who carry out intensive yam cultivation for sale, but only consume it during famine (Muller, 2005). Yam is a highly solicited prestigious component of the diet, consumed by all but mostly producers and persons with a high purchasing power, considering the relatively higher cost of tubers compared with other food crops such as cereals and cassava.

The Baka pigmies of East Cameroon also exploit many wild varieties of yam for food and medicines. This is the case with *D. praehensilis,* which is used as an important starchy food, while toxic varieties are used to poison their arrows which are used for hunting (Dounias, 2001).

YAM STORAGE AND MARKETING IN CAMEROON

Storage practices

Many farmers lack adequate yam storage facilities, and have resorted to on-farm conservation of ware and seed yams. In this case tubers are left inside the soil when vines dry-off. The farmer regularly passes around to assess and cut-off sprouting shoots. Other traditional methods include silos, heap on the soil, straw shelter, shelves, and clay barns (Ngue-Bissa et al*.,* 2007). Traditional yam storage practices do not provide enough protection against rot and pests, and do not facilitate regular inspection, in order to detect damage and prevent excessive weight loss by tubers. It is necessary to improve yam storage to reduce post-harvest losses, optimize yields of the crop and consequently, encourage farmers who are key actors in the yam production chain in the country.

Yam marketing

Tubers of five main yam varieties (*D. rotundata, D. alata, D. cayenensis, D. bulbifera, and D. dumetorum)* are those commonly sold in Cameroonian markets*.* However, there is no standard yam market in the country. According to Ngassam et al*.* (2007), any location where yam producers and buyer's carryout their interactions maybe considered as a market or transaction point. These include farm gates, road sides (between production areas and urban cities or markets), and organized markets (local/retail markets found in villages, secondary whole sale markets based in rural areas, and terminal markets found in main towns of the country). Ngassam et al*.* (2007) also reported the existence of 53 yam markets in Cameroon, 38 of which are retail markets, 13 secondary and two terminal whole sale markets. In the country, 21% of yams are sold at farm gates, 11% at road sides and 68% in markets. Road side yam sales points in the Southwest Region are found along the Ekondi-Titi – Kumba – Buea – Douala highway; in northern part of the country along the Ngaoundere – Mbe – Garoua highway; and in the Centre region along the Mbangassina – Bafia – Ombessa – Obala – Yaounde highway.

Local markets are found in most villages where they are organized at least once a week, and help to supply whole sale markets. Secondary markets in Penda Mboko, Muea, Muyuka, and Mbonge supply whole sale markets in Douala, Yaounde, Bafoussam, Bamenda, Gabon and Equitorial Guinea. Those in Mbangassina, Ntui, Ombessa, Okola, Pouma and Mbankomo supply Yaounde; and the ones in Ngaounyanga, SasaMbersi, Karna Manga, and Wack supply Ngaoundere, Garoua, Maroua, Kousseri, Tchad, and Central African Republic.

Terminal wholesale markets are found at main towns of the country: Bafoussam, Bamenda, Bertoua, Buea, Douala, Garoua, Maroua, Ngoundere and Yaounde. However, adapted terminal wholesale markets are lacking. One of the wholesale market located at "Ancienne Gare de New Bell" in Douala, like others, lacks buildings with hygienic conditions needed to handle yam tubers.

Lack of markets (as in Mann, Sir, Deyna and Toubaga in Mbe plain), coupled with poor road networks, long distances to nearest markets, inadequate and poorly adapted transportation facilities, and heavy weight of tubers (Ngassam et al*.,* 2007), limit farmers' ability to move their goods to the markets. They are forced to sell their crops at farm gates, sometimes at very low prizes which discourage further investment in yam cultivation. Also, production basins are highly disconnected, making it impossible for farmers from different basins to interact and exchange ideas and planting material to enhance production and render yam cultivation more profitable.

Seignobos (1998) reported that 3 to 5 tubers of *Bakokae* were sold at 1500 CFA (US $2.6) in 1988. In 1997, following devaluation of the CFA, the same number of tubers of *Bakokae* and those from Nigeria were sold at 1500 CFA (US $2.6) to 2000 CFA (US $3.5) and *Ngang* at 500 CFA (US $0.9). Presently, ware yam tuber prices vary greatly with zones and seasons. During harvest, heaps of 3 to 5 medium size tubers are sold at 2000 CFA (US $3.5) at road side markets in Adamawa Region (Figure 2). The prices are much higher at terminal markets, ranging from 1000 CFA (US $1.7) for medium size tubers to 4500 CFA (US $7.8) or more for larger ones (Figure 2). At the local markets, seed yams are generally not sold as individual seeds but mostly in basins, baskets or heaps, which vary in prize from one zone to the other. Acquah and Evange (1991) reported a breakeven prize of 236.6 CFA (US $0.41) per seed yam in Fako Division, South West Region of Cameroon. The yam marketing system is not well coordinated, not adequate, and adapted markets are lacking. This makes it difficult for small holder yam farmers to reap optimum benefits from the activity.

GENETIC DIVERSITY AND CONSERVATION (GENEBANK) OF YAMS IN CAMEROON

Genetic diversity of yams in Cameroon

Cameroon has a very wide diversity of cultivated and wild edible yam species and varieties. Lyonga (1976) reported the existence of nine cultivated yam species in

Cameroon, which are: *Dioscorea rotundata* (white yam), *D. alata* (water yam), *D. cayenensis* (yellow yam), *D. dumetorum* (sweet yam or cluster yam), *D. bulbifera* (aerial yam), *D. esculenta* (Chinese yam), *D. trifida, D. librechtsiana,* and *D. schimperiana.* Of these nine species; *D. rotundata*, *D. dumetorum*, *D. alata*, *D. cayenensis* are the most popular species (Ngeve, 1998; Ngo-Ngwe et al*.,* 2014). *Dioscorea trifida,* which was introduced in the 1970s, remained with the research program and might have been lost from the germplasm (Lyonga, 1976) due to lack of maintenance. Aerial yam is mostly cultivated as well as exists in the wild in the southern parts of the country, and *D. dumetorum* is most adapted to high altitude savannah zone (Northwest and West Regions). *D. alata*, *D. rotundata*, and *D. cayenensis* are cultivated in almost all agro-ecological zones of the country (Ngeve, 1998).

Cultivated yam species are composed of many cultivars, whose names vary with national languages (French and English), nearly 250 local languages and source of the cultivar. Some cultivars of *D. rotundata* are thus called *Bakokae* and *Ngang* in the Adamawa (Seignobos, 1998; Dansi et al*.,* 2001), *Calabar, Malende, Oshie, Mbot, Bonakanda* (*Agar*) in the southern parts of the country (Lyonga, 1976; Mignouna et al*.,* 2002). Similarly, some cultivars of *D. cayenensis* are called "*igname jaune*" and *Batibo*; those of *D. alata* called *Ogoja* (Lyonga, 1976) and *D. dumetorum* called "*igname sucrée*" or *sweet yam*. Sometimes different names may as well refer to the same cultivar, thereby creating confusion in assigning local landraces to given species. The most popular cultivar of *D. rotundata* are; *Bakokae, malende, Bonakanda* and *Calabar* yam*; D. cayenensis* are *Batibo* or *Nkambe* (commonly called yellow yam or Igname jaune); *D. alata* is *Ogoja.* Amongst these cultivated yam species, *Oshie* and *Mbot* are recommended for plateau regions and *Bonakanda* and *Ogoja* for lowlands, while *Batibo* is suitable for the plateau regions (Lyonga, 1976). More trials with other varieties need to be conducted, so as to determine the most adapted for each agro-ecological zone, and consequently, improve on yam production.

Dumont et al*.* (1994) reported the existence of high yam diversity in Cameroon, with 16 yam species. Dounias (2001) also reported the existence 17 probable rainforest wild yam species, among which 10 are edible and are exploited by Baka pigmies for food (Hladik and Dounias, 1996; Sato, 2001; Yasuoka, 2013). These edible varieties include *D. hirtiflora* Benth, *D. semperflorens* Uline, *D. praehensilis* Benth, *D. mangenotiana* Miège, *D. burkilliana* Miège (KeKe), *D. minutiflora* Engl, De Wild and Dur, and three uncharacterized species.

Further, DNA analysis using flow cytometry has indicated four ploidy levels among accessions of four yam species from Cameroon. The ploidy levels include diploid (*D. dumetorum*), tetraploid (*D. cayenensis, D. rotundata*and *D. alata*), hexaploids (*D. alata and D. rotundata*) and octoploids (*D. cayenensis*) (Ngo-Ngwe et al., 2014). Contrary to previous reports of triploids, pentaploids or octoploids among *D. alata* collections from Chad, Puerto (Muthamia et al*.,* 2014) and IITA Ibadan (Obidiegwu et al*.,* 2009b); Cameroon accessions lack these ploidy levels. Furthermore, only diploids have been reported among *D. dumetorum* collection in Cameroon (Ngo-Ngwe et al*.,* 2014), yet Obidiegwu et al*.* (2009a), reported the existence of triploids in IITA collection. Dansi et al*.* (2001), using flow cytometry, also reported three ploidy levels (tetraploid, hexaploid and octaploid) in the *D. rotundata-cayenensis* complex from Cameroon. Siadjeu et al*.* (2015), using morphological descriptors, reported a high genetic diversity in a collection of *D. dumetorum*in Cameroon. Mignouna et al*.* (1998), from nuclear DNA analysis, using amplified fragment length polymorphism (AFLP), reported that *Bakokae* cultivar of Cameroon is a close genetic relative of *cv Noworfon* from Nigeria, *Gnidou* and *Terkokonou* from Benin and *cv Zrezou* from Côte d'Ivoire. Based on chloroplast DNA analysis of eight yam species from Cameroon, *D. esculenta* has the lowest phylogenetic diversity while *D. cayenensis* and *D. praehensilis* (a wild species) have the highest phylogenetic diversity (Ngo-Ngwe et al*.,* 2015).

These high ploidy levels amongst and across yam species, in addition to the taxonomically complex nature of the genus, with a wide number of species and high morphological diversity (Mignouna et al*.,* 2002), coupled with varying cultivar names render assessment of genetic diversity of yams in the country more challenging. Considering the importance of genetic diversity in yam breeding programs and yam biodiversity conservation, it is important for more elaborate and robust genetic studies with morphological and molecular markers associated to gain more insight into the genetic diversity of yams in Cameroon.

Conservation of Cameroon's yam cultivars (Yam genebank)

Although there have been indications of a wide diversity of yam species and varieties in Cameroon, cultivated yams in the country seem to have suffered from serious genetic erosion. Elite species such as *D. rotundata, D. cayenensis D. dumetorum D. alata D. bulbifera* are available all over, but others such as *D. esculenta, D. trifida, D. liebrechtsiana,* and *D. schimperiana* are rare, and might have been completely lost due to lack of maintenance. This has been due to lack of interest in yam research and conservation. Yam production is left in the hands of peasant farmers who may have access only to a single variety (where alternatives are not available), or use their own local criteria to select varieties they can cultivate, at the detriment of others which are left to be eroded away. There have been many attempts in

Cameroon, to collect and preserve yam germplasm. Lyonga (1976) established a germplasm collection made of 89 accessions, 11 varieties (eight local and three exotic), and nine yam species: *D. alata, D. bulbifera, D. cayenensis, D. dumetorum, D. esculenta, D. liebrechtsiana, D. rotundata, D. shimperiana and D. trifida* (Lyonga et al*.,* 1973). Other attempts to collect and preserve yam germplasm have been carried out at IRAD Bambui and Ekona as well as IITA. These collections seem to have been maintained only in the field (where they are exposed to a lot of environmental stress), without any back-up in the form of *in-vitro* culture or in cryopreservation.

Generally, these yam germplasm collections have often not included wild and sometimes edible species, which have high phylogenetic diversity and provide important resource material for breeding programs. Due to difficulties to maintain yam germplasm collection in the field, a yam genebank does not exist in Cameroon today. This absence of a yam genebank, which is a prerequisite to any yam breeding program, has probably contributed to the low yam production level in the country. This calls for an urgent need for surveys, collection, characterization and maintenance of a complete yam germplasm collection for Cameroon.

SEED SYSTEMS, GENOMICS AND YAM IMPROVEMENT

Literature indicates that yam farmers in Cameroon procure their planting material, mainly through traditional informal seed systems (sorting, weaning, junking, kin heritage, donation from friends, buying from markets, and domestication), without any quality control. Farmers reserve about a half or more of their year's harvest to use as seeds for the next planting. This traditional seed systems favour the accumulation of pre- and post-harvest diseases (fungal, bacterial, nematodes, viral) and pests, rendering planting material to lose its viability, and leads to sub-optimal yields and post-harvest tuber loss. The seed system is also characterized by low propagation rates (Balogun et al*.,* 2014). But a major pre-requisite for improved yam productivity, production and storability is the availability of high quality improved planting material (genotypes). The use of minisett technology and in-vitro culture (rarely used in the country) contribute in increasing the seed yam propagation rate, but do not have provision of cleaning infected seed yams and are genotype-dependent as well. New genetic and genomics technologies such as marker assisted selection, genetic engineering and genome editing are important tools in developing improved plant varieties (Ronald, 2014). These improved varieties are equipped with desirable traits that render the yams high yielding with enhanced nutritional content to reduce the land area exploited for agriculture; resistant to pre- and post-harvest pest and diseases to reduce yield loss while improving storability; and tolerant to environmental stress.

Among pathogens of yam diseases, viruses which reduce yield and hamper exchange of germplasm belong to six different genera and are genetically and serologically very heterogeneous with reports of the host (*Dioscorea* spp.) genome containing endogenous pararetroviruses (Bousalem et al*.,* 2009). This complicates diagnosis using the conventional nucleic acid-based and serological tools: Enzyme-linked immunosorbent assay (ELISA), polymerase chain reaction (PCR), rolling cycle amplification, recombinase polymerase amplification (RPA), which target known viruses. These still allow the spread of viruses through planting material, even those generated by *in-vitro* culture. Next generation sequencing technology which help to detect novel and pararetroviruses in planting material including *in-vitro* culture generated ones (Bömer et al*.,* 2018), will help to produce clean seed yams to boost yam production.

CONSTRAINTS TO YAM PRODUCTION IN CAMEROON

Constraints to yam production in Cameroon include; high labour cost and requirement, lack of mechanization, high cost and scarcity of seeds, poor soil fertility, pre- and post-harvest pests (insects, nematodes, rodents) and diseases (viral and fungal), lack of adequate conservation facilities, absence of improved (high yielding and disease-resistant) varieties, absence of coordinated research, and unavailable or poorly coordinated and adapted markets (Lyonga, 1976; Ngeve,1998; Ngassam et al*.,* 2007). Diseases are a very important constraint to yam production, which affects yield and quality of tubers. These diseases include anthracnose caused by (*Colletotrichum gloeosporioides*), tuber rot caused by different soil-borne fungi (e.g. *Aspergillus niger*) (Dania et al., 2016) and yam mosaic virus disease complex.

Yam virus disease has been reported to be a very important constraint to yam production, with yield loss of over 50% reported on *D. rotundata*, due to infection by *Yam mosaic virus* (YMV)*,* genus *Potyvirus* and *Cucumber mosaic virus* (CMV) - *genus* Cucumovirus (Adeniji et al*.,* 2012) in other countries of the West African yam zone, where there is regular uncertified exchange of yam germplasm (accompanied with viruses) through unchecked land borders. Viruses infect yam singly or mixed and include members of the genera *Cucumovirus, Badnavirus, Potyvirus, Macluravirus, Comovirus and Potexvirus* which have been reported in most surveys (Njukeng et al*.,* 2014). These viruses produce varying symptoms (including mosaic, shoe-stringing, chlorotic spotting, leaf crinkling, mottling, stunting) on the plants, reduce plant vigour and consequently, cause a reduction in yield and quality (Adeniji et al*.,* 2012; Njukeng et al*.,* 2014). Mvila (1991) reported the occurrence of yam mosaic disease in two regions of Cameroon and Offei

(2003) reported the occurrence of Yam virus 1(YV1) in Cameroon. Recently, Njukeng et al. (2014) reported a high incidence (81.7%) and distribution of YMV and yam badnaviruses (YBV) infecting yams in two agro-ecological zones of the country. These researchers indicate a high incidence of single infection by YMV (52%), YBV (66.2%) and mixed infection of both viruses (36.2%). However, this review indicates that research on yam virus diseases in Cameroon is still very scanty. Considering the fact that many viruses have been identified in other countries of the African yam zone where there is uncontrolled exchange of germplasm (accompanied by viruses) through unchecked land borders, it will be important to enhance research on yam virus diseases in Cameroon, to promote control measures to limit the spread and effects of these viruses within the sub region.

RESEARCH ON YAM IN CAMEROON

According to Ufuan (2010 unpublished) in a baseline survey on the capacity for yam research in Cameroon's Universities, research institutes and Non-governmental organizations (NGOs), on-going research work related to yam is scanty and current research activities on the crop are focused on nutrition, agronomy, entomology, production, agricultural economics, and postharvest technology, and marketing. It is clear from the survey that less than 30 researchers are involved in yam research and that most of these researchers are either aging and/or are part-timers. Similarly, very few students are carrying out graduate and post-graduate research related to yam (Ufuan and Njualem, 2010).

CONCLUSION

Based on the forgoing presentation of the state of yam in Cameroon, it is evident that yam production has very high potentials in alleviating poverty and improving food security in Cameroon. Cameroon has a huge diversity of yam genotypes which can be exploited in yam breeding programs. However, yam production has not been maximized due to several challenges imposed by the nature of the crop and low R & D investments on yam crop improvement. All stakeholders in the yam production chain need concerted efforts to enhance yam production in the country. Adequate funding is of capital importance.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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Full Length Research Paper

Sensory profile of coffees of different cultivars, plant exposure and post-harvest

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The processes of maturation, harvest and post-harvest coffee of are strictly related to the physical and chemical modifications that can affect the sensorial quality of the coffee, being decisive factors in the choice of the appropriate management to reach the desired quality standard. The objective of this research was to identify the sensorial attributes of the Coffee Association of American (SCAA) protocol of coffee cultivars grown in the same geographic space, with fruit collection on two faces of exposure to solar radiation from the same plants subsequent post-harvest processing by wet and dry route. The study was conducted in Minas Gerais, in the city of Monte Carmelo. Six cultivars of *Coffea arabica* L. species were evaluated. The fruit collection in two exhibitions faces the solar radiation from the same plants with subsequent post-harvest processing via wet and dry. In view of the results it can be concluded that there was a better discrimination of sensory attributes among postharvest cafes obtained in the sun face plant processes, the cultivar Obatã had the highest final score between the years of assessment and all cultivars showed potential for the production of specialty coffees, with the lowest scores attributed to genetic material Iapar-59.

Key words: *Coffeea arabica* L., specialty coffees, sensory evaluation, specialty coffee association of America, quality.

INTRODUCTION

The demand for specialty coffees in the market has increased much more compared to the commodity coffee and are characterized by high quality, excellent flavor potential after roasting, absence of any defects and their relation with specific origin, culture or genotypes. In order to evaluate the quality of the samples, the quality of the samples was determined by genetic methods (Villarreal et al. 2009), environmental (Alonso-Salces et al., 2009) and postharvest (Duarte et al., 2010; Jöet et al., 2010a, b).

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The environmental, genetic and technological factors are related to the quality of the coffee, by the contribution in the formation of the sensorial attributes. It is important to emphasize that the planting direction of the coffee tree can alter the intensity of diseases in the aerial part, according to the exposure of the face of the plant to the solar radiation that modifies the period of wetting and shading of the leaves, causing quantitative losses in the production and quality of the final product (Custódio et al., 2010).

In the region of Cerrado Mineiro are produced very high-quality coffees, with different flavors and aroma. The increasing participation of specialty coffees in the national and international markets requires research that identifies the most promising cultivars and the best type of post-harvest processing that result in differentiated coffees with higher commercial value.

The processes of maturation, harvest and post-harvest are strictly related to the physical and chemical modifications that can affect the sensorial quality of the coffee, being decisive factors in the choice of the appropriate management to reach the desired quality standard. For the coffee, the quality of the beverage determines its desirability for consumption purposes and acts as a reference point for the determination of the price (Gimichu et al., 2012).

It is observed that, despite the different researches related to the description of the sensorial profile, the interaction of the different cultivars for the production of special coffees is not understandable, through the specific post-harvest processing, as well as, if the exposure side of the plants in relation to the nascent / west sun can influence the sensorial attributes of coffee.

In this context, the objective of this research was to identify the sensorial attributes of the Coffee Association of American (SCAA) protocol of coffee cultivars grown in the same geographic space, with fruit collection on two faces of exposure to solar radiation from the same plants subsequent post-harvest processing by wet and dry route.

MATERIALS AND METHODS

The experiment was carried out in Minas Gerais, in the municipality of Monte Carmelo in the Brazil six cultivars of *Coffea arabica* L. (Iapar 59, Paraíso MG H 419-1, Obatã IAC 1669-20, Catuaí Vermelho IAC-144, Bourbon Amarelo and Topázio MG 1190) were evaluated in the years 2011 and 2012.

First, the boundary space was delimited in the field of each cultivar, with three initial lines after the "carrier" and three plants in the "interlining" to start the collection. Nine plant lines were demarcated with 30 m in length and every three lines corresponded to a field plot. The harvesting of the mature fruits was made selective and manual, in all cultivars, in a period of 48 h, only in the middle third of the plants, separating the exposure faces of the lines facing the morning sun from the faces facing the shade of the (planting in the North/South direction) and submitted to two post-harvest processes, via wet and dry, resulting in 72 samples (6 cultivars × 2 exposure faces × 2 processing). After harvesting the ripe, green and dry fruitsthe samples were transferred, removing the remaining green fruits, besides the hydraulic separation of the drier fruits in gallons of 100 L of water. Each plot resulted in 20 L of ripe fruit.

In the drying of the samples, suspended yards were used with 1.2 m of height to 804 m of altitude in relation to the level of the sea and with distributions for each sample. The natural and demucilated coffee were stirred 12 times a day (Malta, 2011). The drying layer for the natural coffee was from "fruit to fruit" in the first two days for the superficial dehydration and day after day the layers were folded up to the measure of 5 cm of height, with the fruits already in stage "passes" in the drying. After the fifth day of drying, the fruits received a covering consisting of raffia bag (for retention of condensed water by fruit mass) and canvas (thermal insulation), both cleaned (Malta, 2011). The same procedure was adopted for the natural coffees for the demucilated coffee samples, however, the folding of the layers and the covering began on the second day of drying. All samples were covered at 3:30 p.m. for the use of the heat retained in the mass of the fruits during the day in the evening and discovered at 08:00 p.m. to avoid absorption of local moisture by the fruits (Malta, 2011).

Such procedures were followed until the coffee samples reached the water content of 11% (b.u). The samples were collected, stored in coconut (natural coffees) and parchment (demucilated coffees) in paper bags covered with polyethylene plastic bags, for 60 days, in a storage room climatized at 15°C, free of light, located at the Pole of Technology in Coffee Quality - UFLA. After this period, the samples were carefully benefited at the Coffee Post-Harvest Technology Center - UFLA. For the sensorial analyzes only the grains retained in the 16/64 inch screen were used. All extrinsic and intrinsic defects were removed, in addition to the molasses grains, for better sample uniformity. The water content of the raw coffee beans was determined in an oven at 105 ± 1°C for 16±0.5 h, according to the international standard method of ISO 6673 (International Organization For Standardization - ISO, 1999).

Sensorial analyzes were carried out in the 2011/2012 and 2012/2013 agricultural crops, conducted by qualified and accredited tasters for the evaluation of specialty coffees (Q-Graders), using the methodology proposed by the American Association of Special Coffees - SCAA (Lingle, 2011).

Firstly, a correlation matrix, organized in a graphical arrangement called the corgram, was evaluated in the experimental conditions (Face and Via) to verify the concordance of the tester's notes. The principal component analysis technique was used to eliminate highly correlated variables. Thus, for each year, the Biplots charts were constituted assuming the first two components.

Later, given the selection of the variables via biplots, for each sensory attribute, the effect of the cultivars was evaluated for the effects of each sensory attribute in relation to the annual average, using the main effects graphs whose interpretation is suggested in Montegomery (1997). Due to the fact that the experiment involves several factors, which would lead to an analysis of variance with interactions of order higher than three, we opted for graphic analysis of the effects.

Finally, in order to identify the cultivar that presented the best indexes for the sensorial attributes evaluated, we proceeded to use the multidimensional scaling technique given the formation of predictive axes built on the scale of each attribute. All statistical methods, used in the analysis of sensory data, were performed in Software R Core Team (2013).

RESULTS AND DISCUSSION

The statistical model, expressed in graphs 1 and 2,

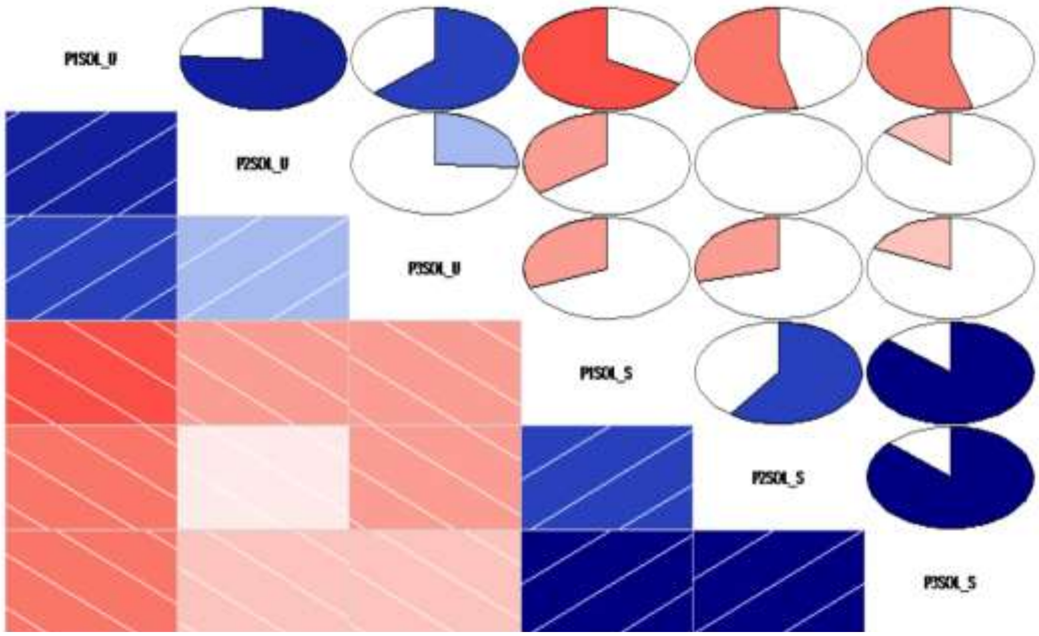

Figure 1. Graph of the correlation between the tasters' response to the final score in relation to the evaluated coffees fixed to the sun face. P1 - Tester 1; P2 - Tester 2; P3 - Tester 3; SOL_U- Fruits of the sun face processed by Wet way; SOL_S - Fruits of the Face Sun Processed by dry way.

makes it possible to verify the similarity between the scores given by the testers when setting one of the factors adopted in the field procedures. This fact is perceptible, when evaluating the coloration of the circular graphs in shades of blue, indicating a strong correlation in the final scores, as well as the representativeness in the clockwise direction of the color. The results showed that, for all evaluated coffees, the probes P1, P2 and P3 present similar responses in relation to the coffees that were submitted to the experimental conditions given by the humid way.

By isolating the scores given by the accredited evaluators between Umida and Seca process routes for sun face, there was lower concordance between the scores, visualized by the coloration in red tones, which, by presenting more intense tones in the anti-clockwise direction, parity between scores. These results express the reliability of the data because the different types of post-harvest processing contribute to the occurrence of various metabolic processes within the fruits of the coffee tree, significantly altering the chemical composition of the raw grain and, consequently, the sensorial attributes after (Bytof et al., 2007).

By keeping the shade face fixed, by means of the results shown in Figure 2, a discrimination of the tasters between the coffees produced in the wet and dry way again is observed, so that the final notes were strongly correlated and positive, a since the angle in the clockwise direction is higher with greater blue color, with emphasis on the fittings P2 and P3.

The biplots presented were constructed according to the first two main components obtained in relation to the sensorial attributes, results shown in Figures 3 and 4. Given this quality of fit considered adequate, it can be affirmed, through the values of the angles between the vectors, that the variable final score is highly correlated with flavor and overall impression. Similarly, the correlation between aroma and body, balance and finalization is noted.

All of the correlations, however were positive, indicating that all of the sensory attributes are important components in determining beverage quality, corroborating the results of several other studies of C. arabica genotypes (Kathurima et al., 2009; Sobreira et al., 2015a). However, these correlations are only indicative of associations among the various attributes and do not reveal cause and effect relationships. For this, analysis of the direct and indirect effects among the variables is required, in order to identify the most effective selection criteria.

The attribute of flavor represents the intensity, quality, and complexity of the combination of all of the attributes, whereas Ccp refers to the absence of negative impressions during ingestion and Swt refers to the pleasantness of the taste, which is the result of them presence of certain carbohydrates. Bitterness (or “green”

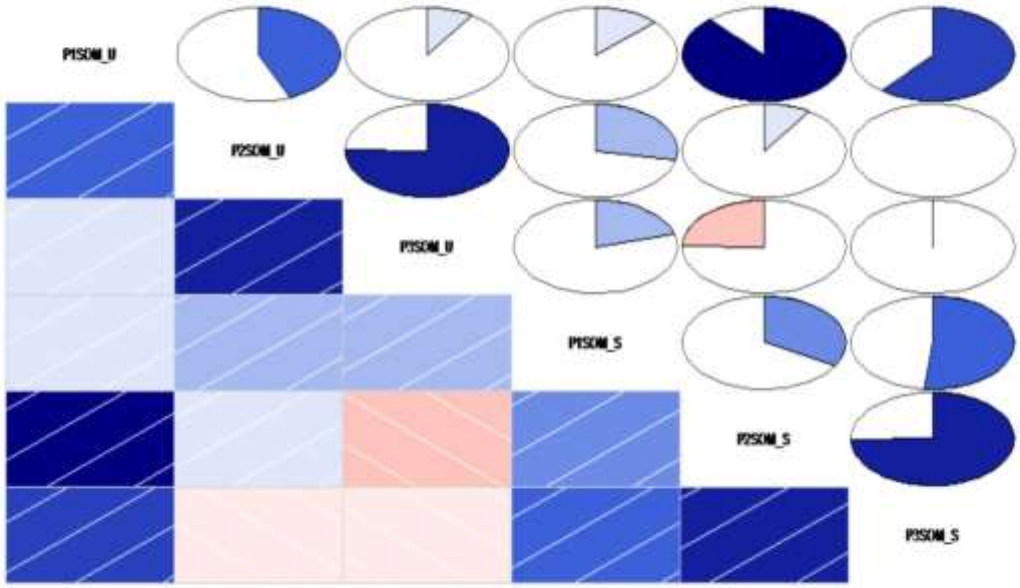

Figure 2. Graph of the correlation between the tasters' response to the final score in relation to the evaluated cavities fixed to the shadow face. P1 - Tester 1; P2 - Tester 2; P3 - Tester 3; SOM_U-shade fruits processed by wet way; SOM_S - shade fruits processed by dry way.

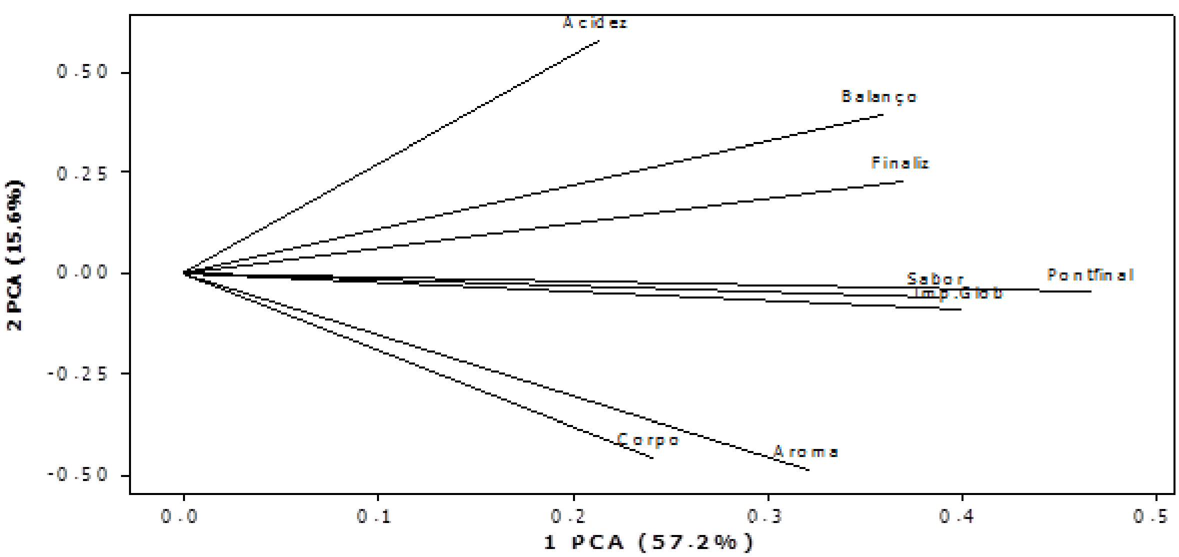

Figure 3. Biplots for the sensorial attributes for the year 2011.

flavor) in this context is the opposite of Swt (SCAA, 2014). Such terms are commonly used by both professional coffee tasters and researchers involved in analyses of the sensory qualities of coffee (Kitzberger et al., 2011; Gamboa et al., 2013).

As a function of the correlation analysis of the sensorial attributes made each year (Figures 3 and 4) in order to evaluate the effect of exposure factors and processing pathway for each cultivar, it was decided to verify the effect of the variables: final score, balance, acidity and aroma/fragrance, since the other variables are strongly correlated with some of these variables, and it is therefore considered redundant to use them in the statistical analysis. In light of the aforementioned, the

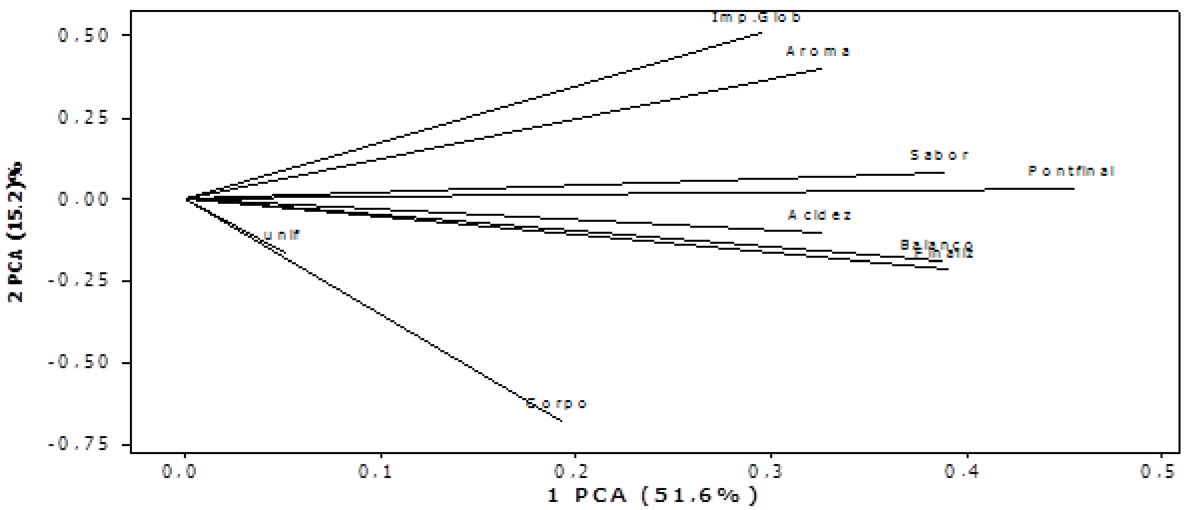

Figure 4. Biplots for sensory attributes for year 2012.

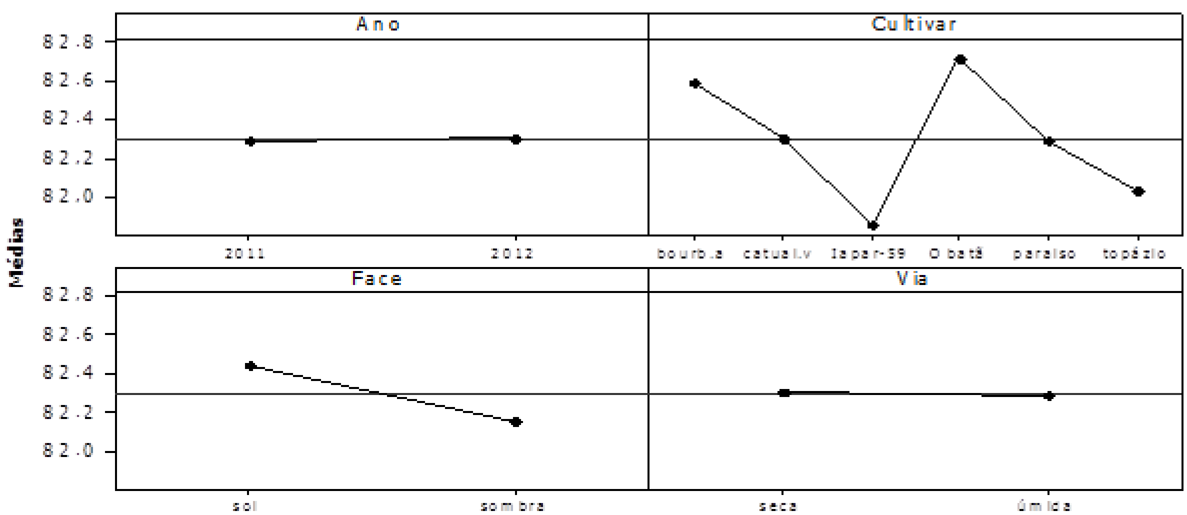

Figure 5. Graph of the main effects for the variable final score.

effects illustrated in Figures 5 to 8 were analyzed.

The results shown in Figure 5 show that the effect of the exposure faces was similar in relation to the annual average when addressing the variable final score, a fact that is verified by the similar distances of the points in relation to the central axis. It was observed that, for the average of the years, the cultivar effect was more pronounced for the final score, especially the cultivars Iapar-59 and Obatã.

It should be emphasized that the quality of specialty coffees is related to the intrinsic characteristics of the grains, which have chemical compounds that, after roasting, will provide aroma, flavor, acidity, sweetness and bitterness to the beverage, in addition to the synthesis, the accumulation and the degradation of the chemical compounds of the raw coffee grain, considered as precursors of the flavor and aroma of the beverage, depend on the genotype and environment interaction (Taveira et al., 2014).

In the same context, the main effects for the balance attribute are included (Figure 6), when observing the same genetic materials there was a grouped symmetry in relation to the distance of the mean axis. The cultivars, Obatã and Iapar 59, Paraíso and Catuaí Vermelho,

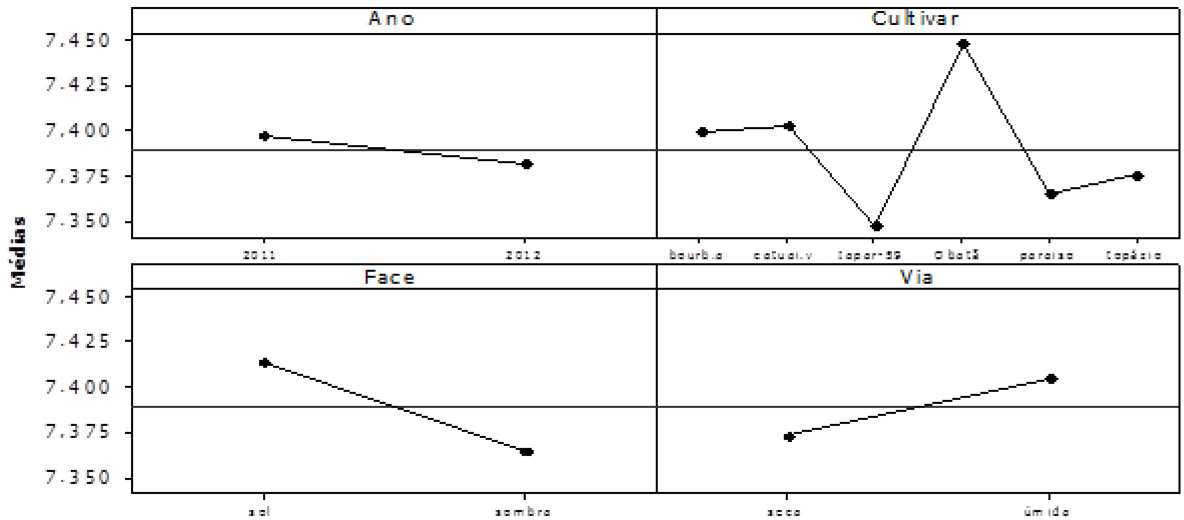

Figure 6. Graph of the main effects for the balance variable.

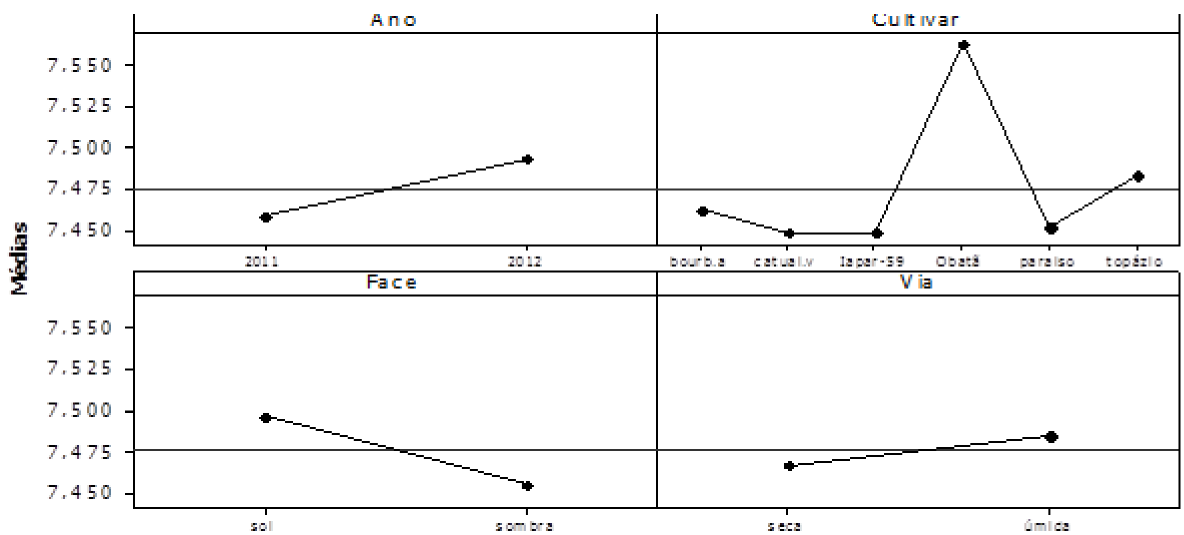

Figure 7. Graph of the main effects for the variable acidity.

Topázio and Yellow Bourbon presented subtle similarity in relation to the distance of the average axis in relation to the annual average.

In Figures 7 and 8 the main effects for acidity and aroma/fragrance are, respectively expressed. The effects of wet/dry and sun/shade, also, were similar in relation to the year, however, the cultivars with the highest highlights were Obatã and Bourbon yellow, respectively. He verified in analyzes of the sensorial profiles of dry and wet processed coffee that the coffees processed by the humid route were more aromatic with fruity and acidic attributes and had less bitter, burnt and woody notes (Duarte et al., 2010)

Both attributes are essential, when in adequate quality and intensity, to obtain special coffees. Possibly the altitude cultivation of 892 meters may have contributed with the highest acidity for the cultivar Obatã in relation to the other genetic materials. The coffee aroma is affected by several factors from the field to the cup (Sunarharum et al., 2014), however the post-harvest processing of coffee is another point that has a significant impact on the coffee aroma (Bhumiratana et al., 2011).

Sobreira et al. (2015b) divides the acidity category into the three subcategories alive, sweet, and undefined/

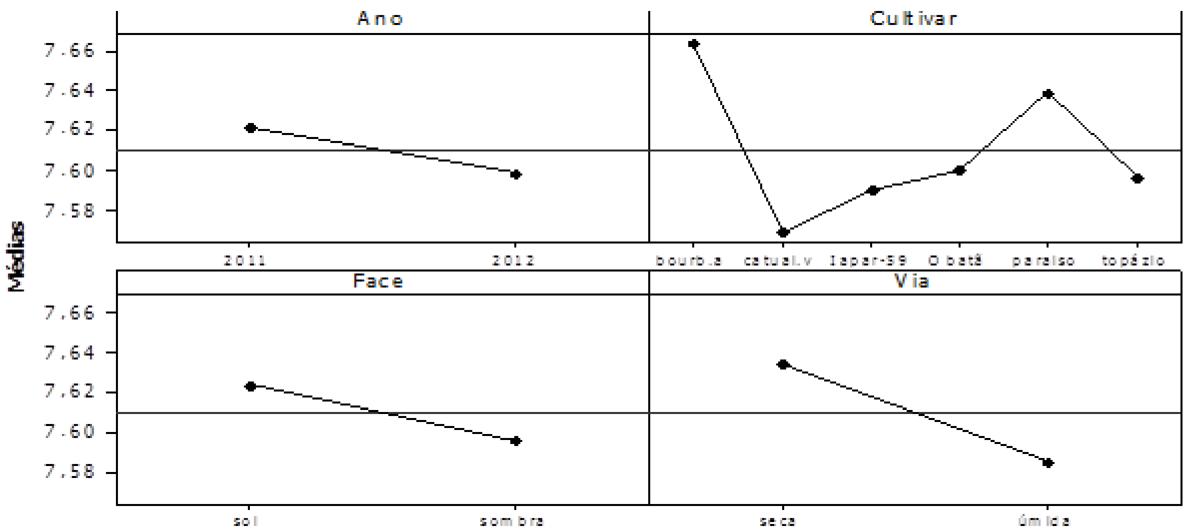

Figure 8. Graph of the main effects for the aroma/fragrance variable.

medium, flavor into chocolaty, fruity, and caramel, and aftertaste into long, refreshing, and pleasant. In this paper, these three categories; acidity, flavor, and aftertaste, were considered to be decisive in determining the final score of the beverage. Kathurima et al. (2009), in a study of 42 genotypes of *C. arabica* in Kenya, observed that aftertaste, acidity, and flavor correlated strongest with quality, a result similar to ours. Likewise, in a similar study, Sobreira et al. (2015a) observed that aftertaste and flavor correlated highly with quality for the germplasm Timor hybrid.

The results observed in the sensorial analyze of coffees cultivated at different altitudes in the municipality of Patrocínio - MG showed that the altitude increased the acidity profile of the beverage, which contributes to coffee quality.

The biplot with multidimensional scaling (Figure 9) shows that all the cultivars under study presented potential for the production of specialty coffees, since the final score given by the tasters according to the protocol of the Specialty Coffee Association of America was above 80 points.

According to the BSCA methodology, final scores must be higher than 80 for classification as specialty coffee (Chalfoun et al., 2013). Scores between 71 and 75 were assigned to hard beverage, 75 to 79 for only soft drink, 80 to 84 for soft drink, and above 85 for strictly soft drink (Martinez et al., 2014)

By the average of the treatments, according to the cultivar, the final scores, given by the tasters, were higher to grow Obatã. The cultivars Topázio, Paraíso, Catuaí Vermelho and Bourbon Amarelo were awarded intermediate and increasing grades, which according to Lingle (2011), according to the SCAA protocol, the coffees are considered as special.

Fassio et al. (2016), while assessing these same cultivars in Lavras and Patrocínio, gave Catiguá MG2, Paraíso MG H419-1, and Araponga MG1 the highest sensory scores, and Sobreira et al. (2015b) found that cultivars deriving from Timor hybrid de scored higher than traditional and Bourbon cultivars.

The highest acidity is observed in the beverage obtained by the cultivar Obatã, as well as for the balance attribute. It can be noticed that the attributes with the nearest median grades were for Catuaí Vermelho, a genetic material widely cultivated in Brazil. The yellow Bourbon presented the highest notes of fragrance/aroma attribute and the lowest were found for the cultivar Iapar 59, when analyzing the average of all the treatments for the same genotype.

The quality of the beverage is the product of the sum of the sensory attributes of the coffee beans, and this is correlated with the geographical area where the plants are grown (Scholz et al., 2011), and all these factors give the product a unique identity that defines the final quality (Silva et al., 2015). Then, it can be considered that these plantations are areas with marked characteristics for the production (Gamonal et al., 2017), where special and high-quality coffees can be obtained.

For crops such as coffee, Zou et al. (2012) stated that the location where the crop is grown determines the final quality and defines the subsequent processes that the product needs to be subjected to before consumption. According to Rolle et al. (2012) by adding information on the geographical origin of an agricultural product facilitates its acceptance in the market.

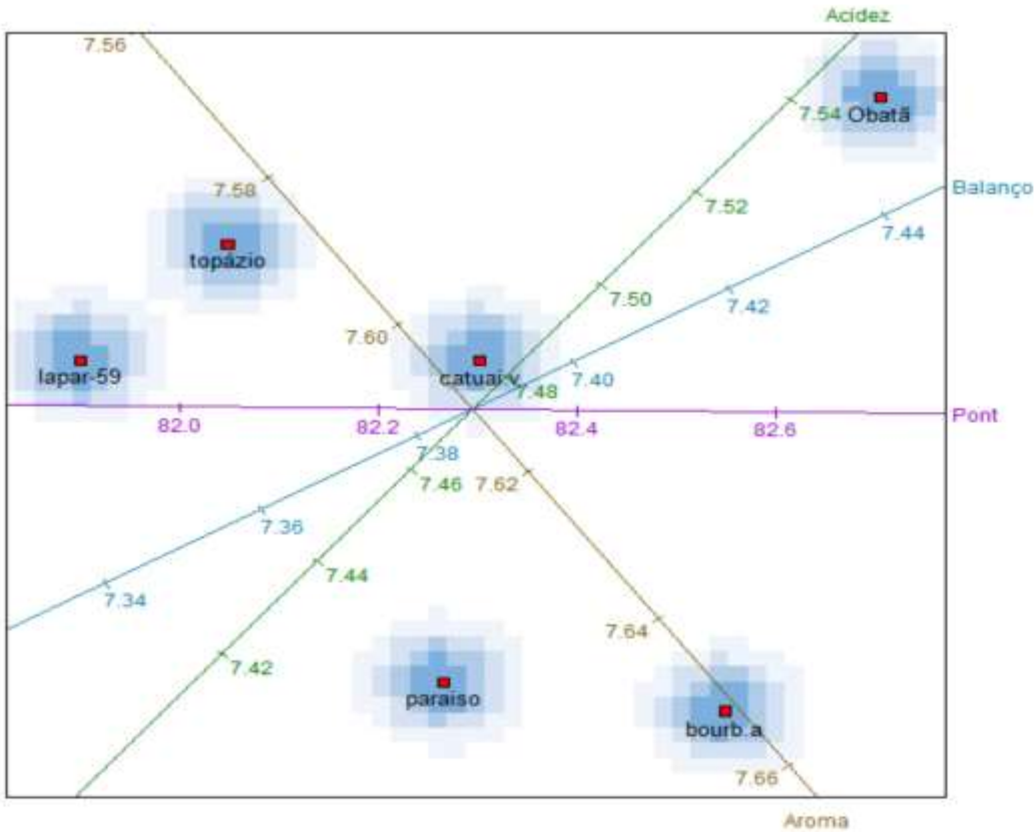

Figure 9. Biplot with multidimensional scaling for the cultivars as a function of the sensorial attributes.

Conclusion

All cultivars presented potential for the production of specialty coffees with notes above 81 points by the SCAA protocol, with particularities differentiated between attributes in the context of quality, intensity and exoticity.

The main effects for final score and acidity, as well as balance and aroma/fragrance attributes were more expressive and pronounced for the cultivars Obatã, and Yellow Bourbon, respectively. The agreement between the final scores of the tasters was more noticeable when fixing the sun face in relation to the post-harvest processing.

CONFLICT OF INTEREST

The authors have not declared any conflict of interest.

ACKNOWLEDGEMENT

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Full Length Research Paper

Tenure security, investment and the productivity of agricultural farms in the communal area of Kavango West Region of Namibia: Any evidence of causality

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The study determines whether there are causal influences amongst the decision to apply for leasehold land right, investment, and livestock farm productivity in the Kavango West Region of Namibia. Various econometrics models have been used to model these relationships in the literature. However, there is a growing concern that methods which do not explicitly account for the endogeneity of regressors and which are used to investigate the relationship between property rights and the economic activities on agricultural farms often produce bias estimates that are inefficient and inconsistent. This study applied an instrumental variable (IV) regression to a survey data of 510 farmers to correct for endogeneity. A test of endogeneity of tenure security, investment, and farm productivity in the various models show that tenure security is exogenous to farm investment decision and farm productivity. On the other hand, farm investment decision was found to be exogenous to farm productivity, which implies that farmers make investment decisions given a secure tenure right that enhances their productivity on the farm. Overall, there was no evidence to support reverse causality in any of the tests. These findings highlight the importance of secure property rights as being a stimulus for increased agricultural investment and productivity.

Key words: Property right, tenure security, endogenous, exogenous, investment.

INTRODUCTION

Since Namibia gained independence in 1990, the issue of land reform has been the government's top priority, aimed at redressing the skewed land ownership orchestrated by the apartheid government. An early attempt was the call for a National Land Conference in 1991, which resolved a comprehensive programme of

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commercial land reform. According to Sherborne (2017), at the time of the conference, the land audit showed that out of a total of 6,292 number of farms, 6,123 were privately (white) owned, whereas, a mere 181 were owned by communal (black) farmers (Sherborne, 2017). This disparity in land ownership resulted in the call for a policy reform which culminated in the promulgation of the Communal Land Reform Act (CLRA) in 2002. Under the CLRA (Act No. 5 of 2002), the rights that may be allocated to individuals comprise: a) a customary land right, b) a leasehold right and c) an occupational land right. An occupational land right is granted to not-for-profit social development projects such as churches, schools, hospitals and recreational parks. Customary land rights assign rights to establish homesteads for residential purposes and subsistence agricultural purposes on lands adjacent to residential areas. Leasehold rights are issued for land that is intended for business enterprise development, such as farms in the communal areas[1]. Leasehold rights are issued for a typical period of 25 years, up to a maximum of 99 years[2]. On expiration of the lease, the holder can reapply for a grant of leasehold rights.

In addition to these initiatives, the issue of strengthening property rights has been enshrined in the constitution of Namibia. Article 16 of the constitution commits the government to guarantee the rights of all persons to own private property, as well as to pay just compensation for all land acquired through land reform initiatives (The Republic of Namibia, 2002). Article 100 and Schedule 5 recognise communal land ownership. Consequently, the Communal Land Reform Act (CLRA) (Act No. 5 of 2002) was enacted to deal with the administration and management of communal land. The Act is administered through the Communal Land Board, whose functions among other things are:

a) to exercise control over the allocation and the cancellation of customary land rights by chiefs or traditional authorities under the CLRA (Act No. 5 of 2002),
b) to consider and decide on applications for leasehold rights under the CLRA (Act No. 5 of 2002), and
c) to establish and maintain a register, and a system of registration for recording, the allocation, transfer, and cancellation of customary land rights and leasehold rights under the CLRA (Act No. 5 of 2002).

Article 66 of the Namibian constitution protects and recognises customary laws that are not in conflict with the constitution or any other statutory laws of Namibia, thus recognising traditional authorities through the Traditional Authorities Act (Act No. 25 of 2000). The traditional authorities comprise the chiefs, senior headmen and head women, village headmen and head women, and community leaders. They exercise a considerable amount of control over land use and transfer, as allowed to them under the Traditional Authorities Act (Act No. 25 of 2000) and the CLRA (Act No. 5 of 2002), with reasonable checks and balances being provided under Article 18 of the Namibian constitution.

Further steps to redress skewed land distribution within the confines of CLRA included the introduction of the communal land registration programme in March 2003 under the communal land development programme. This programme involves the registration of customary, occupational and leaseholds land rights. The programme aims to give increased access to communal land by the previously disadvantaged people, with the aim that this will stimulate investment and productivity in the rural economy. Prior to the reform programme, there was no tight control over land in Namibia (Werner et al., 1990). There was a disparity in the acquisition of land rights. For instance, while the commercial or freehold land is surveyed and registered, the communal land is not. As a result, uncertainty over the rights of ownership arises, resulting in tenure insecurity, boundary disputes, low investment and poor land management.

Nonetheless, traditional authorities may issue land rights[3] under the Traditional Authorities Act (Act No. 25 of 2000). The leasehold land rights issued before 2002 by a chief or by the Ministry of Land and Resettlement (with permission to occupy (PTO) certificates) are operationally tenure insecure because they are not held under secure tenure rights. However, an occupant who had held leasehold land in this manner for a period longer than ten years would then acquire a legal claim over the land. In other words, prior to reaching the landmark of 10 years, farmers would not make fixed improvements on the land for fear of losing them during appropriation. After 2002, PTOs ceased to have effect unless the land under leasehold has been registered. The registration programme serves to enhance tenure security for beneficiaries, thereby giving them legal documentary proof to the land, preventing conflicts arising between landowners and intruders, and conferring on them the opportunity to invest. Investments in this regard include those that facilitate productivity, such as fencing, boreholes, farmhouses and electricity generators. For a livestock farm, a fence provides security while excluding intruders and a borehole and water reticulation provide water supply via an on-farm alternative energy generator. Other investments include capital investment such as purchasing bulls, weighing scales and other on-farm facilities. All these investment activities are assumed to

[1]. For the rest of this paper, the emphasis is placed on the leasehold right, which is the central theme of this research.

[2]. It can only terminate when the person dies, and can be transferred to the heir subject to fresh application. The period is determined by Act of the Parliament, and not by any person or entity.

[3] Which are a form of leasehold or letter of consent, and not a land right

be facilitated by the presence of a leasehold right, whereby the holder can generate a decent income, create employment opportunities and contribute to the growth and the development of the economy of the country.

Nevertheless, the land registration process is not devoid of controversy. There is a concern that the amounts of leasehold land allocated through registration are meagre[4]. Therefore, the registration exercise has not resulted in huge success in most areas. Consequently, there was a recent call for a second land conference that was held in August 2018. Given this prevailing circumstance, this research seeks to investigate the tenure security-investment-productivity nexus. The aim is to determine whether the uncertainty in land distribution has resulted in a shift in the common nexus among tenure security, investment and farm productivity. Therefore, the question is whether all the land beneficiaries did invest in land, and how productive those who invested are. Some highlights from the CLRA (Act No. 5 2002) show that land rights:

(a) Cannot be registered as legal deeds and as such cannot be used as surety in any transaction;
(b) They are not freely tradable; and
(c) In terms of termination upon death, land may be reclaimed by chiefs, even when transferred to an heir unless he/she has applied for it.

Factors such as these can destroy the incentive to invest in the land. However, the strength of the evidence in support of this claim is not known with certainty. The answer to these questions is what motivates the study. Although the application is on data generated in Namibia, its entirety is novel and applies to what is obtained elsewhere. Namibia is chosen as a case study, firstly, because it has a history of land deprivations and, as previously stated, the skewness in land ownership is high. Secondly, the economy is dualistic, with the minority represented by established commercial farmers who hold large portions of land, while the majority are peasant, mainly subsistent, communal farmers with limited access to land. Thirdly, in 2007, some parts of Namibia, namely the Kavango, Ohangwena, Zambezi, Omusati, and Omaheke were designated and gazetted as small-scale commercial farming areas in the communal areas, with the aim of transforming farmers in these areas from communal farmers into commercial livestock farming entrepreneurs.

In this regard, the study empirically investigates leasehold land ownership in the communal area, using various econometric tests. The aim is to determine the relationship among tenure security, farm investment and productivity in the livestock sector in the Kavango West region (North of the Veterinary Condor Fence (NVCF)) of Namibia, where no known evidence exists of a similar study. In this region, leasehold rights are held by the private communal farmers, who are often referred to as Small-Scale Commercial Farmers[5] (SSCFs). An SSCF, though subject to registration, may make improvements on the farm. On the other hand, communal farms may not, because of tenure insecurity. However, there may be an exception because, in some areas, fixed improvements have been effected on communal land (including fencing) by households who claim to have permission to do so from the relevant authority[6]. The study investigates the circumstances of such occurrences and the effect they may have on investment and productivity in the selected region.

LITERATURE REVIEW

The issues of property rights, tenure security, farm investments, and agricultural productivity are central to land reform and agrarian transformation. Property rights confer rights to use the land, but exclude the rights to transfer the land or its output to other users (Demsetz, 1967; Alchian and Demsetz, 1973; Norton and Alwang, 1993). A typical right to transfer includes the rights to sell, rent, inherit, pledge, mortgage, and offer the land as a gift. Implicitly, secured property rights bestow tenure security (given appropriate tenure reform) on the holders; this facilitates investment and productivity on the land. However, many schools of thought argue that this framework is location-specific. However, the mixed empirical analytical underpinnings of these schools of thought and the available stylised fact are not sufficient to comprehensively assess the links amongst property rights, tenure security, investment, and agricultural productivity (Besley, 1995; Roth et al., 1989; Holden and Ghebru, 2016). For instance, Feder and Onchan (1987) found that ownership of land title increased capital accumulation and investment in Indonesia. According to Roth et al. (1989), title ownership is not synonymous with tenure security. In some instances, the property right may be usufructuary in nature, which is granted to operators as long as they remain on the land, and this is the situation in Ghana (Besley, 1995). Under the usufructuary arrangement, tenure system may be weak and confer rights that are to some extent tenure insecure (Besley, 1995). Under insecure tenure, there will be uncertainty in the traditional tenure system. Uncertainty in the traditional tenure system may destroy incentives to invest because

[4]. A maximum of 50 hectares is stated to be allocated per person. Hence, landholders are reluctant to apply to the Land Board.

[5]. The scenario is different in the Southern Veterinary Condor Fence (SVCF). In the SVCF, there are both commercial and communal farms with fixed farm improvements such as fencing and farmhouse, with or without leasehold. This is rarely applicable in the NVCF; hence, this study focused on farms in a specific region in the NVCF (Kavango West) which have the most significant number of farmers with leasehold certificates.

[6] The legality of this claim is questionable, and it is not observed everywhere.

operators are afraid of the loss of land and property due to land eviction and appropriation. As mentioned earlier, this situation applies to Namibia.

Nonetheless, in some instances (with no exceptions to Namibia), an investment may be made to secure the right to the land (Besley, 1995; Brasselle et al., 2002; Place and Otsuka, 2001; Atwood, 1990). This implies that there may be no clear practical evidence that secured land tenure enhances investments and agricultural productivity; hence, tenure rights may be endogenous to investment (Besley 1995; Place and Hazell, 1993; Bruce 1988). Other studies with similar findings are those of Do and Lyer (2008) for Vietnam; Brasselle et al. (2002) for Burkina Faso, and Gavian and Ehui (1999) for Ethiopia. Contrary to these findings, operators with stronger user tenure rights to land are likely to invest more resources and increase their productivity (Deininger and Jin, 2006; Deininger et al., 2008). Studies by Smith (2004) in Zambia; Gebremedhin and Swinton (2003) in Ethiopia; and Graham and Darroch (2001) in South Africa have shown that land tenure security enhances investments and agricultural productivity. Other studies with similar findings are those of Alemu (2000); Awudu et al. (2010); Besley (1995); Dercon and Ayalew (2005) and Mwakubo (2002).

With due consideration of the mixed findings, an important question to be answered in this study is whether there is a causal link amongst tenure security, investment, and increased farm productivity. In other words, does tenure security stimulate investment and farm productivity? Is there a reverse causality amongst these variables of interest?

The model

The formulation of models in the literature for the estimation of the relationships amongst property rights, investment and productivity follow a system of simultaneous equation modelling. Simultaneous Equation Models (SEMs) applied by Feder and Onchan (1987); Place and Hazell (1993); Place and Migot-Adholla (1998) are widely used in the literature to model optimisation problems involving farm investments and production decisions, with or without tenure rights. The general assumption underlying the SEM specification in the literature is that tenure security (TS) increases farmers' capacity to obtain credit (C) used to finance farm investment (I) for optimal productivity (Y). Farmers are risk-averse and are assumed to maximise income, output and net welfare subject to constraints, which might include access to credit. In the models, tenure security (TS) is assumed to be exogenous to credit (C), investment (I) and productivity (Y). Credit (C) is assumed to be exogenous to Investment (I) and productivity (Y) because farmers obtain credit to finance investment and productivity. Investment (I), Credit (C) and Tenure security (TS) are exogenous to productivity. An investment fund may include production credit; therefore, credit (C) is assumed to be exogenous. Tenure security may directly or indirectly affect productivity through increased investment. It may affect it directly because farmers with insecure tenure rights may decide not to produce at all. The variables TS, C, I, and Y all depend on sets of exogenous variables such as household (HH) and farm characteristics (F). It is assumed that the way in which farmers understand the nature of their tenure rights will influence their households' (HH) investment decisions. If farmers perceive tenure as being insecure (Feder and Onchan, 1987), and being risk-averse, they would invest in movable capital assets, which can be retrieved in case of farm loss through eviction or appropriation.

On the other hand, fixed investments, such as land improvements (fences, trees and boreholes) and operational cost outlays are lost during evictions. Farmers are unlikely to invest in fixed assets unless there is a high level of trust in the tenure right, which might be weak and unreliable. The SEM for the above formulations can be represented with the following structural models:

Credit model: $C = f(HH, F, TS)$, (1)

Investment model: $I = f(HH, F, C, TS)$, (2)

Productivity model: $Y = f(C, I, TS, HH, F)$, (3)

The variables in these models are defined above. Reduced forms of the models (1) to (3) have been used to model different types of tenure rights (freehold, leasehold, customary etc.), investments (short-term and long-term) and credit markets (institutional and non-institutional). By assumption, reduced-form equations are estimated by expressing tenure security in terms of credit and investment on the right-hand side of equations (1) to (3) (Place and Migot-Adholla, 1998; Dube and Guveya, 2013; Hayes et al., 1997). In some studies, a reduced-form recursive regression of the models has been used. For instance in Dlamini and Masuku (2011), the fitted values (or even residuals) were recursively included in Equations (2) and (3), instead of the actual C and I variables.

This study used a treatment effect and instrumental variable method to establish relationship and to model endogeneity of regressors of interest. The Instrumental Variable (IV) estimator provides consistent estimates conditional on the presence of a valid instrument. Consider the equation:

$$y = \beta_1 + \beta_2 x_1 + \beta_3 x_2 +, ..., \beta_k x_k + \mu \qquad (4)$$

Where, x_1 and x_2 are endogenous and exogenous variables, respectively. A suitable instrument says z is chosen to correlate with x_1 and not μ so that the estimator will be a consistent estimator of β_2. To ensure there is no endogeneity in the regressors, the IV method regresses y on χ variables using z, such that $E(\mu_i \mid z_i) = 0$. To identify the estimable simultaneous equation model (SEM), the order condition of identifiability was applied to ensure that the model is either exactly identified (EIM) or over-identified (OIM).

Data and sampling

The study was carried out in the Kavango West Region of Namibia. The Kavango West Region has eight constituencies: Kapako, Mankumpi, Mpungu, Musese, Ncamangoro, Ncuncuni, Nkurenkuru and Tondoro. The Kavango West is situated in North-eastern Namibia. The region covers an area of about 24591.27 km² and lies directly south of Angola, overlying the Kavango River (Ministry of Land and Resettlement MoLR, 2015). It is a semi-arid region with an average summer temperature of about 30°C. Although the 2011 census and regional profile of the region show that about 53% of the agricultural households are crop farmers, greater income is

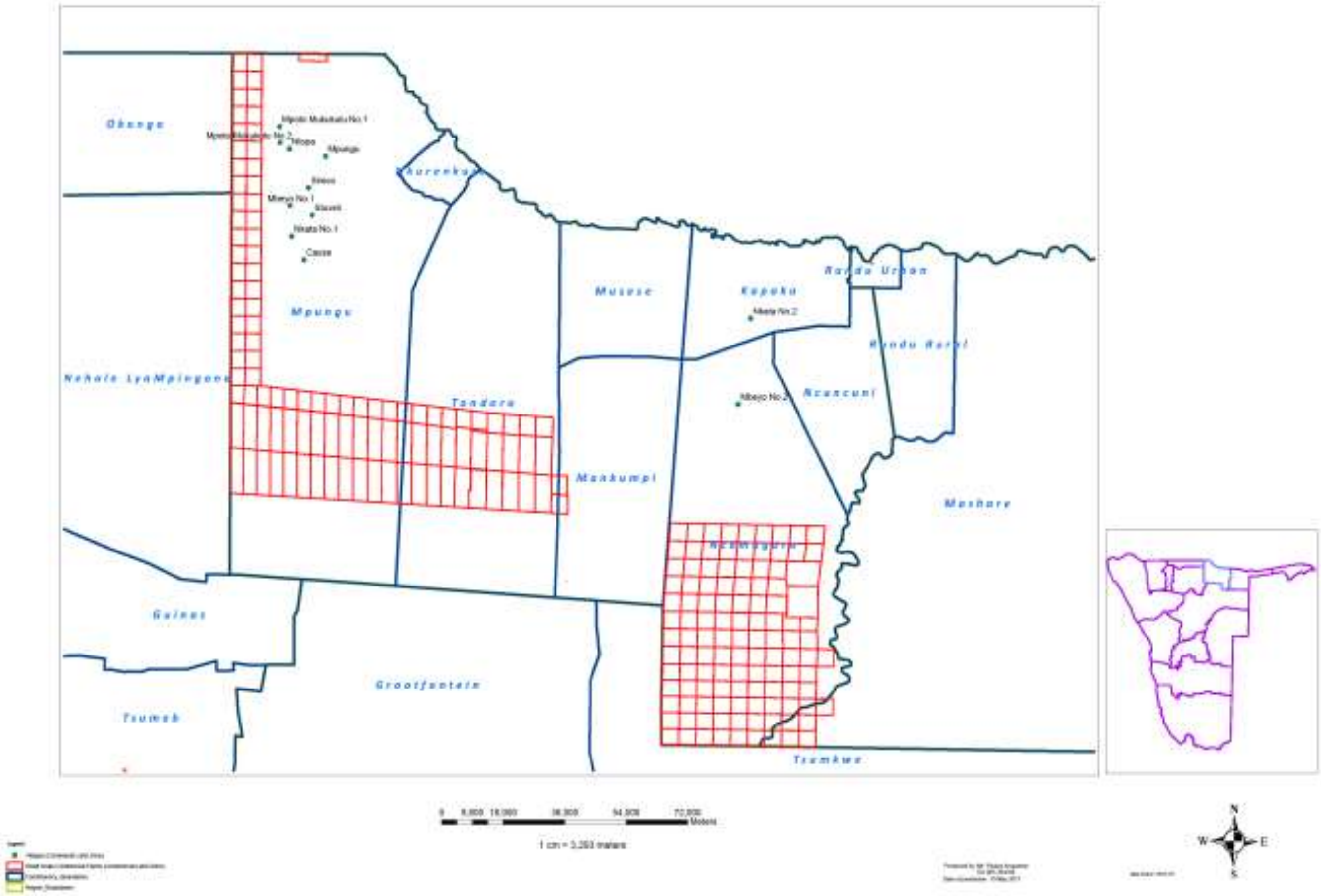

Figure 1. Study area: Private (SSCFU) and communal (village) land zones. Source: Author's computation.

generated from livestock enterprises than crop farming, which makes up 22.8%; while poultry constitutes only 7.9% of the total household participation in agriculture. Livestock were chosen for this study because of their importance as a significant income-generating enterprise in the region and the country at large, as well as the fact that the region is one of the regions in the country with the highest numbers of livestock farmers with leasehold certificates (562). Open access to communal land constitutes 45.7% of the land in the region, whereas the small-scale commercial farmers in this community make up 29.6% (Ministry of Land and Resettlement MoLR, 2015).

The data collection was conducted using a survey method. A multistage sampling method was adopted. First, the respondents were stratified by gender. Second, simple random sampling was used to select respondents who were to be interviewed. Data were collected through a questionnaire administered by trained enumerators. The enumeration was carried out in nine villages from the Mpungu constituency namely, Cause, Mbeyo, Mpoto, Mpungu, Munkala, Nkata, Ntopa, Simco and Situvel, as shown in Figure 1. In total, 510 respondents were randomly selected and interviewed, of whom 255 were private small-scale commercial farmers with leasehold rights, and 255 communal farmers without leasehold rights. The aim is to compare the level of investment and productivity between the two groups and relate them to the presence or absence of tenure rights.

RESULTS AND DISCUSSION

Descriptive statistics

The information gathered from the survey consists of the farmers' demographic characteristics, availability of tenure certificate, farm investment, credit, and farm productivity. Farmers' demographics include age, education, household size, experience, and income. It is assumed that experience comes with age, and that with better education, experienced farmers make better decisions. If farmers earn high income from their farming enterprise, they would probably seek a secure property right to optimise investment and productivity. They may likely become more risk-averse when they are older, as compared to the younger adventurous farmers. The survey shows that the average age of the respondents on a private farm is 51 years, whereas communal farmers are on average 54 years old. On average, a typical private farmer has attained at least grade 12 education, compared to the communal farmers' average school achievement of grade 8. The average household size for

Table 1. Summary statistics.

Items	Description	Mean	Std. Error	Median	Std. Dev	Min	Max
Gender	Categorical*	0.7	0.0	1.0	0.5	0.0	1.0
Education	Categorical	10.1	0.2	12.0	4.9	0.0	19.0
Age	Continuous	52.4	0.5	53.0	11.4	29.0	86.0
Household size	Continuous	5.1	0.1	4.0	2.3	2.0	16.0
Farm Experience	Continuous	21.0	0.4	21.0	8.4	1.0	41.0
Tenure Security	Categorical	0.5	0.0	0.5	0.5	0.0	1.0
Fence	Categorical	0.5	0.0	0.0	0.5	0.0	1.0
Borehole	Categorical	0.2	0.0	0.0	0.4	0.0	1.0
Farm House	Categorical	0.7	0.0	1.0	0.4	0.0	1.0
Electricity Generator	Categorical	0.1	0.0	0.0	0.3	0.0	1.0
Solar Energy	Categorical	0.1	0.0	0.0	0.3	0.0	1.0
Water Pipes Roll	Categorical	0.1	0.0	0.0	0.2	0.0	1.0
Water Tank	Categorical	0.1	0.0	0.0	0.3	0.0	1.0
Goats	Categorical	0.2	0.0	0.0	0.6	0.0	6.0
Cattle	Categorical	0.0	0.0	0.0	0.2	0.0	1.0
Bull	Categorical	0.0	0.0	0.0	0.2	0.0	1.0
Feed Supplements (N$)	Continuous	0.1	0.0	0.0	0.3	0.0	1.0
Medicine & Pesticides (N$)	Continuous	0.0	0.0	0.0	0.2	0.0	1.0
Non-farm Income (N$)	Continuous	79742.8	5758.7	33000.0	130050.4	0.0	1207895.0
Total Income (N$)	Continuous	88891.3	6231.5	41500.0	140727.4	1.0	1207895.0
Total Production	Continuous	61.2	3.3	22.5	73.4	1.0	429.0
Calving Rate	Continuous	0.3	0.0	0.3	0.1	0.0	0.6
Support service	Categorical	0.5	0.0	0.0	0.5	0.0	1.0
Farm Credit	Categorical	0.2	0.0	0.0	0.4	0.0	1.0
Operating expense (N$)	Continuous	217.0	57.0	0.0	1288.0	0.0	18900.0
Capital Invest. (N$)	Continuous	1408.7	306.8	0.0	6927.8	0.0	85200.0
Loan (N$)	Continuous	24845.4	2946.2	0.0	66535.4	0.0	425000.0
Fence cost (N$)	Continuous	26568.3	2810.0	0.0	63457.9	0.0	1000000.0
Borehole cost (N$)	Continuous	16395.8	1703.2	0.0	38463.5	0.0	230000.0
Farm house cost (N$)	Continuous	5769.2	520.2	2500.0	11746.8	0.0	109000.0
Generator cost (N$)	Continuous	1207.9	203.6	0.0	4596.8	0.0	60000.0
Solar panel cost (N$)	Continuous	950.6	179.1	0.0	4044.4	0.0	50000.0
Water Pipes cost (N$)	Continuous	119.6	29.9	0.0	675.7	0.0	10000.0
Water trough cost (N$)	Continuous	79.8	30.3	0.0	685.0	0.0	11000.0
Water Tank cost (N$)	Continuous	950.8	133.7	0.0	3019.6	0.0	27000.0
Goat cost (N$)	Continuous	618.4	164.1	0.0	3706.0	0.0	72500.0
Cattle cost (N$)	Continuous	338.4	138.9	0.0	3136.3	0.0	50000.0
Supplement cost (N$)	Continuous	187.4	54.1	0.0	1222.2	0.0	18000.0
Bull cost (N$)	Continuous	1108.2	338.8	0.0	7651.3	0.0	94000.0
Medicine cost (N$)	Continuous	33.1	9.6	0.0	217.7	0.0	3100.0

*Categorical variable take the value of 1, if the event occurred, zero otherwise

both types of farmers is 5 (Table 1). According to the table, the mean farm experience is 21 years for both types of farmers. This is an indication of the presence of a generation of young farmers in the study area. On and off-farm income is high and the highest income is more than a million Namibian dollars. As expected, fixed improvements constitute the bulk of farm expenditure compared to the operational expenditure. The percentage changes in the various income and expenditure items for the farms are given in Tables 2 and 3. The Tables show the differences in farm operations between private farmers who have tenure certificates and communal farmers who do not.

As previously mentioned, a measure of the property

Table 2. Farm tenure, investments and other activities as a percentage of the total.

Activities	Items	Private farms (%)	Communal farms (%)	Total
Tenure	Tenure certificate	100	0	100
Farm investment types	Fence	100	0	100
	Borehole	90	10	100
	Farm House	32	68	100
	Electric Generator	80	20	100
	Solar Energy	93	7	100
	Water Pipes	73	27	100
	Water Tank	95	5	100
Capital investment	Goats	55	45	100
	Cattle	58	42	100
	Bull	94	6	100
Farm inputs	Feed Sup	98	2	100
	Medicine and pesticides	83	17	100
Farm Income	Non-Farm income	88	12	100
	Farm-Income	86	14	100
Productivity	Production	91	9	100
Farm credit	Farm Loan	100	0	100

Table 3. Investment costs as a percentage of total.

Activities	Items	Private farms (%)	Communal farms (%)	Total
Farm investment types	Fence	100	0	100
	Borehole	100	0	100
	Farm house	39	61	100
	Electricity generator	86	14	100
	Solar Energy panel	97	3	100
	Water Pipe	56	44	100
	Water trough	81	19	100
	Water Tank	97	3	100
Capital Investment	Goats	84	16	100
	Cattle	95	5	100
	Bull	99	1	100
Variable costs	Feed Supplements	99	1	100
	Medicine	92	8	100

rights in the study area was obtained by interviewing farmers who had applied for and obtained leasehold certificate and those who had not. The record shows that the farmers that have leasehold certificates had obtained them during the years 2000 to 2016. Farm fixed investments include fences, boreholes, water troughs, water tanks, farmhouses, solar panels, and electric generators for an alternative energy source. These investment parameters are dummy variable, where 1 indicates a farmer made investments, and zero otherwise.

The farmers' fixed investment activities recorded as a percentage of total fixed investments are shown in Table 2. The table shows that private farmers with leasehold certificates had more fixed farm investments than communal farmers. In the real communal system, livestock is raised on open range land; hence, none of the communal farmers had a fence. More numbers of communal farmers made an investment in a farmhouse than the private farmers because in most cases, their farm is situated around their homestead.

Another type of farm investment includes capital investment (such as the purchase of cattle, bulls, goats and sheep) and farm inputs (feed supplements, licks, medicines, pesticides etc.). The details in Table 2 show that the private farms invested more resources in these capital assets than the communal farmers. This is perhaps due to financial leverage derivable from the credit market because a property right (secure tenure) may serve as collateral for a loan (Table 2). On the other hand, none of the communal farmers had obtained any form of credit from any source, as shown in Table 2. A measure of output per input used is shown in Table 2. The table shows that private farms are more productive than the communal farms as shown by the total numbers of livestock produced, income and non-farm incomes. Output (productivity) is a continuous variable – a measure of the total number of livestock produced (herd size) during the survey period. The costs for both fixed and capital investments are shown in Table 3. As expected, the percentage of cost outlay for the private farms outweighs that for the communal farms. The reason is, as explained previously, private farmers invest more resources and have more cost outlays than the communal farmers have.

Regression analysis

In this section, a causal relationship among the variables (tenure security, farm investment, and productivity) was investigated. It is observed that there were too many categorical investment variables to be included as indicators in the investment model. Including the entire catalogue of variables might introduce bias. Therefore, the dimensionality of the variables was reduced using a Principal Component Analysis (PCA) method. The PCA analysis of the investment variables resulted in the identification of four principal components and component scores. Other variables, such as the various costs of investment items, were not used in the underlying regression analysis because there were too many observations that are either unobserved or missing. To model the envisaged relationship, various estimators were employed. Firstly, an Ordinary Least Square (OLS) regression was fit. The aim is for this to serve as a starting point for the comparison of the various estimators used in the case of an Exactly Identified Model (EIM). Secondly, an IV regression for the correctly identified model (EIM) was fit. Thirdly, a test of regressor endogeneity was carried out for each pair of the model investigated. For the case of an endogenous binary regressor, a treatment effect causal model was fit; whereas, for a discrete dependent variable model, a linear probability (LPM), a Probit and an IV-Probit choice models were fit. These models were fit for the purpose of comparing the results.

To identify the estimable simultaneous equation model (SEM), the order condition of identifiability was applied to ensure the model is either precisely identified (EIM) or over-identified (OIM). For each model, instruments were first selected and then a case of Exactly Identified Model (EIM) and Over Identified Model (OIM) restriction was conducted[7]. To test for over-identifying restrictions, the following estimators were used: the Two-Stage Least Square (2SLS) corrected for heteroscedasticity; the optimum Generalised Method of Moment (GMM) corrected for heteroscedasticity; the iterated GMM; the optimal GMM with clustered errors (GMM_Cluster); and the 2SLS with errors that do not adjust for heteroscedasticity[8]. The aim of using various estimators is for comparison. The Sargan score test of over-identified restriction rejects the null hypothesis of over-identification in all the tests. The results of the model over-identification restriction tests are shown in Table 4. The instrument, lease period (*LeaseP*), was used to instrument the tenure security variable. Lease period is the period of the leasehold for the farmer, being either 25 years or ninety-nine years. Some farmers have a short lease period (25 years), while some have an extended period (99 years). Therefore, the variable *(LeaseP)* is a dummy that takes the value 1 if the lease period is long (99 years), otherwise zero. The variable *(LeaseP)* was used as an instrument for tenure security because farmers with a long lease have greater tenure security than those with a short lease, and so might invest more resources; hence, in this instance, lease period will correlate with tenure security.

On the other hand, the composite cost of investment (*Cindexts*) and the calving rate (*Calvrate*) were used to instrument investment and productivity variables respectively. The variable (*Cindexts*) is the instrument chosen for an investment variable because the cost of investment is assumed to correlate with investment. On the other hand, the calving rate (*Calvrate*) was chosen to

[7] An SEM model is exactly identified if $K-k=m-1$, it is over-identified if $K-k>m-1$, where, K is the number of exogenous variables in the model plus the intercept, k is the number of exogenous variable in the equation, and m is the number of endogenous variables in the equation (Gujarati and Porter, 2009).

[8] For more on the test for over-identification restriction, readers can consult STATA 13 User's Guide.

Table 4. Sargan test* of over-identified restrictions in IV2SLS Models.

Regressors	Investment		Tenure security		Productivity	
	Tsecurity	Productivity	Investment	Productivity	Investment	Tsecurity
2SLS	19.157(0.0000)	12.5360(0.0004)	0.1138(0.0000)	11.0352(0.0000)	11.5308(0.0007)	28.5876(0.0000)
GMM_het	19.157(0.0000)	12.5360(0.0004)	0.1138(0.0000)	11.0352(0.0009)	11.5308(0.0007)	28.5876(0.0000)
GMM_IGMM	19.34(0.0000)	12.3531(0.0004)	0.1138(0.0000)	10.91(0.0000)	11.46(0.0000)	28.32(0.0000)
GMM_cluster	10.0069(0.0000)	7.7638(0.0053)	0.8699(0.0000)	6.63183(0.0000)	9.14973(0.0025)	15.6491(0.0000)
2SLS_def	34.1311(0.0000)	19.0448(0.0000)	0.8555(0.0000)	10.161(0.0000)	13.3857(0.0000)	37.7805(0.0000)

*Note Sargan test is distributed as Chi-square test with degrees of freedom equal to the number of restrictions. IV Variables: Tsecurity = Lease period (*LeaseP*); Investment = Cost of composite investment (*Cindext*s) and Productivity = Calving rate (*Calvrate*) Figures in parenthesis are p-value.

correlate with livestock production. The results show that using the instrument *LeaseP, Cindexts and Calvrate,* the IV models were exactly identified (Table 4).

Composite investment model

A composite index was constructed by multiplying the principal component variance for each component with the value of component scores for each variable to fit a composite investment model, and this was summed to obtain the index. Following Equation (4), a composite investment model was fit, where the dependent variable y is the investment composite index (*Cindexts),* x_1 is the endogenous variable (*Tsecurity)* and x_2 represents a vector of exogenous variables *(Age, education, household size, experience and extension support).* The period of the lease (*LeaseP)* was used for the instrument *Tsecurity.*

The results of an OLS and an IV 2SLS being an exactly identified model estimation (with robust standard errors after correcting for heteroscedasticity errors) are shown in Table 5. The results show that farming experience and tenure security significantly influence composite investment on the farm. The assumption is that tenure security in this model is endogenous to composite farm investment. If tenure security is exogenous, then the IV 2SLS estimator may still be consistent, but is less efficient than the OLS estimator is. The Hausman endogeneity test is used to test whether a regressor is endogenous or not. The test compares the difference between an IV and an OLS potential endogenous parameter estimates. It is based on the assumption that if the difference between the OLS and IV 2SLS estimates is negligible, then the regressor (for example tenure security) is exogenous. Hence, there is no need to instrument the model otherwise; a significantly large difference between the estimates indicates that it is endogenous[9]. The Hausman test follows a chi-square distribution with a degree of freedom of one. The null hypothesis of the test is that the regressor is exogenous, and rejecting the null confirms endogeneity. Considering the Hausman assumption, Table 5 shows that the difference between the coefficients of *Tsecurity* for both OLS and the IV 2SLS models is 1.24%. The difference is negligible, which is an indication of exogeneity, although more robust test statistics are required. The Hausman test statistic, however, cannot be used because its assumption is too strong, and it may not yield robust standard errors if homoscedasticity and orthogonality are not strictly met. As an alternative, the related Durbin-Wu-Hausman (DWH) test statistics were used (Davidson, 2000). Two DWH tests were calculated, one with ordinary DWH, and another with DWH 2SLS. The DWH and DWH 2SLS tests are reported in Table 5. The results show that exogeneity was not rejected by the DWH test, thus confirming the result obtained previously using the Hausman assumption. However, the DWH 2SLS result rejects the null as opposed to the result obtained with the ordinary DWH test. This may be attributable to a loss of precision because of the additional instrumentation used for

[9] The test statistics for the Hausman test is computed following the assumption that $\hat{V}(\hat{\beta}_{IV}-\hat{\beta}_{OLS})=\hat{V}(\hat{\beta}_{IV})-\hat{V}(\hat{\beta}_{OLS})$; where, $\hat{\beta}$ is the coefficient of the endogenous variable, and $\hat{V}$ is an estimator of the asymptotic variance

Table 5. Investment model: endogeneity test for tenure security and productivity in an investment model.

S/N	Regressors	Endogeneity test-Tenure security					Endogeneity test-Productivity			
		OLS	IV 2SLS (EIM)	DWH Test	DWH 2SLS	TEM	OLS	IV 2SLS (EIM)	DWH Test	DWH 2SLS
1	T security	5.4364***(0.0000)	5.3691 ***(0.0000)	5.3691***(0.0000)						
2	Age	0.1108***(0.0000)	0.1120 ***(0.0000)	0.1120***(0.0000)	0.1853***(0.0000)	0.3730*** (0.0000)	0.1024***(0.0000)	0.1210 ***(0.0000)	0.1210 ***(0.0000)	0.1210***(0.0000)
3	Edu	0.0270 (0.4010)	0.0280 (0.4380)	0.0280 (0.4380)	0.0861***(0.0080)	0.1159 (0.0330)	0.0326(0.3070)	0.0451 (0.1590)	0.0450(0.1590)	0.0451(0.1600)
4	Hhsize	0.0502 (0.5210)	0.0489 (0.5500)	0.0490 (0.5500)	-0.0806 (0.2800)	-0.2576* (0.0530)	0.0598 (0.4160)	0.0397 (0.5910)	0.0397 (0.5910)	-0.0397(0.5890)
5	Farmexp	-0.1775***(0.0000)	-0.1812 **(0.0240)	-0.1812**(0.0240)	-0.4104***(0.0000)	-0.8225*** (0.0000)	-0.2361* (0.0384)	-0.2787*** (0.0000)	-0.2787*** (0.0000)	-0.2787***(0.0000)
6	Extser	0.3628 (0.2010)	0.3625 (0.2090)	0.3625 (0.2090)	0.3532 (0.2250)	-0.1823 (0.6190)	0.3887 (0.1720)	0.3793 (0.1800)	0.3793 (0.1800)	0.3793(0.1820)
7	Constant	-5.5011***(0.0000)	-5.4555***(0.0000)	-5.4555***(0.0000)	-2.3216***(0.0070)	0.2032 (0.8650)	-7.8481 (1.0000)	-6.7776*** (.0000)	-6.7776*** (0.0000)	-6.7776***(0.0000)
8	Leasep				1.8828***(0.0000)	11.4227 (5207.28)				
9	Lntotprod						1.9526*** (0.0000)	1.6057*** (0.0000)	1.6057*** (0.0000)	1.60570.2565)
10	(vhat) ρ				5.4568***(0.0000)					0.4868 *(0.0570)
11	*F-stat*	112.94*** (0.0000)			96.73***(0.0000)		107.81*** (0.0000)		3.6528* (0.0591)	93.69* (0.0000)
12	*Wald (chi2)*		485.22*** (0.0000)	485.22*** (0.0000)		648.94*** (0.0000)		586.71*** (0.0000)	586.71**** (0.0000)	
13	R^2	0.5742	0.5741	0.5741	0.5742		0.5895	0.5861	0.5861	0.5909
14	Score chi2 (1)			0.0031(0.9554)					3.5612*(0.0591)	
15	vhat F-test				59.7000*** 0.0000)					3.65*(0.0565)
16	LR chi2					3.5100*(0.0610)				

Figures in parenthesis are p-values. The signs ***, **, & *, represents 1%, 5% & 10% significant levels respectively.

the IV-2SLS model. To further confirm the results obtained, a treatment effect model (TEM) was fit. This test was conducted because the potentially endogenous variable, *Tsecurity* in the investment model is a binary variable.

This implies that the outcome is observed when *Tsecurity* is 1, (that is, received treatment); otherwise, it is not observed. The test is a Likelihood Ratio (LR) test of independence of errors, which is distributed as chi-square. The null of independence was not rejected at 5% level of significance, but marginally rejected at 10% (Table 5). It should be noted that in the presence of a slight heteroscedastic error, the IV model is more consistent than the TEM is. Therefore, given the Hausman assumption, the DWH test, and the TEM test, there is a strong indication in support of *Tsecurity* exogeneity in the farm investment model.

The same procedure undertaken to test for *Tsecurity* endogeneity in the investment model was applied to test for farm productivity endogeneity in the investment model. Livestock calving rate *(Calvrate)* was used as an instrument in this model. The results are shown in Table 5. The results show that increasing farm productivity will encourage greater composite investment on the farm. The direction of the causality is what the study seeks to establish. Firstly, the coefficient for the production parameter in both OLS and IV2SLS was compared (Table 5). There was a significantly large difference between the coefficients of *Lntotprod* (about 18%). Following the Hausman assumptions, this is an indication of farm productivity endogeneity in the composite investment model. Secondly, endogeneity tests using DWH and DWH 2SLS test statistics rejected farm productivity exogeneity in the composite investment model (Table 5). It can be concluded that farmers make their production decisions based on the level of investment they have made on the farm.

Tenure security model

This section tests whether composite investment and farm productivity are endogenous to tenure security. To achieve this, a tenure security model was deployed following Equation (4), where the dependent variable y is tenure security *(Tsecurity),* x_1 is the endogenous variable (Cindex or Calvrate), and x_2 represents a vector of exogenous variables (*Age, education, household size, experience and extension support*). The composite cost of farm investment (*cindexts*) was used as an instrument for composite investment. The composite cost was computed from the PCA of investment costs, as described previously. The instrument for production, (*Calvrate*), is as explained previously.

A linear probability model LPM and the IV 2SLS estimates are shown in Table 6. Cognisance is taken of the fact that the LPM may not be the most appropriate model for a discrete probability model because the estimates may lie outside the unit circle, or even generate a negative variance. Nevertheless, it was used for comparison with the IV 2SLS, and later with the Probit model. The results of the LPM and the IV 2SLS show that exogenous variables such as age, education, farm experience and household size, significantly influence the decision to apply for a leasehold right. For the test of endogeneity, the DWH and DWH 2SLS tests strongly reject the null hypothesis of exogeneity. This implies that composite farm investment is endogenous to tenure security. Note that, in the previous test, tenure security was found to be exogenous to composite farm investment; therefore, this result is a confirmation that there is a unidirectional causal influence between tenure security and composite farm investment, and not vice versa.

Next, the above regression procedure was repeated for farm total productivity *(Lntotprod)*. The result of the endogeneity test for farm total productivity in a tenure security model is shown in Table 6. Exogenous variables such as age, education, and farm experience influence the decision to apply for a leasehold right. The DWH and the DWH 2SLS reject the null hypothesis of exogeneity (Table 6). This is an indication that farm productivity is endogenously determined where farmers have secure tenure rights.

Productivity model

Following the regression procedure outlined in this section test whether farm investment and tenure security regressors are endogenous in a farm total productivity model. The results of an OLS and IV 2SLS for this model are shown in Table 7. Following the Hausman assumption, a 12% difference was found between the OLS and IV 2SLS estimates for *cindex* (Table 7). The difference is not significantly large, which is an indication that investment is exogenous to production. The result for the DWH test did not reject exogeneity. However, the DWH 2SLS rejects exogeneity. As stated earlier, this might be attributable to the loss of precision resulting from instrumentation. Notwithstanding this, the results of the Hausman assumption and the DWH tests confirm farm investment exogeneity in the farm productivity model.

The second regression model for farm productivity test whether tenure security is endogenous to farm production. The difference between the coefficient of *Tsecurity* in OLS and IV 2SLS regression is negligible (9%). Therefore, tenure security is exogenous in the productivity model. In addition, the null hypothesis of exogeneity was not rejected by the DWH, DWH, 2SLS, and the TEM test statistics (Table 7). Therefore, given the result obtained in this section and that obtained in it can be concluded that tenure security is exogenous to farm production, and that the direction of causality is unidirectional, flowing from tenure security to farm productivity, and not vice versa.

Discrete dependent variable model

Recall that LPM and IV 2SLS estimators were used for the discrete *Tsecurity* model to test for the endogeneity of investment and productivity variables. In this section, discrete probability models are fit to compare and confirm the results obtained previously. Firstly, a Probit model of the discrete dependent variable (*Tsecurity)* on composite investment *(cindex),* total production *(lntotprod)*, and sets of exogenous variables were selected. Secondly, two levels of an IV-Probit procedure, namely ordinary IV-Probit and IV-Probit Two-Step Sequential Estimation (2SSE) were fit. The IV-Probit is a Maximum Likelihood Estimation (MLE) whereas the IV-Probit 2SSE is an alternative procedure with a minimum chi-square estimator. Both estimators have similar distributional assumptions of multivariate normality and homoscedasticity errors. The results are shown in Table 8. Compared with the LPM and IV 2SLS results in Table 6, the coefficients for the LPM, IV 2SLS, the Probit, and the IV-Probit estimators are all statistically significant at 1%, which is an indication of no loss of efficiency in the models (Tables 6 and 8). As in the LPM and IV2SLS estimations, exogenous variables such as age, education, and farm experience, significantly influence the decision to apply for a leasehold right, when using the Probit and the IV-Probit 2SSE estimators. The test of the marginal effect of the probabilities for the Probit, IV-Probit and the IV-Probit 2SSE estimators confirm there is a significant influence exerted by these variables on the decision to apply for leasehold (Table 8). The endogeneity test for investment and productivity in the Tenure security model is shown in Table 8. The result for IV-Probit MLE and the IV-Probit 2SSE are shown in Table 8. The null hypothesis of exogeneity was rejected in all cases, implying that farm composite investment and farm

Table 6. Tenure security model: endogeneity test for investment and productivity in a tenure security model.

S/N	Regressors	Endogeneity Tests - Investment				Endogeneity Tests – Productivity			
		LPM	IV 2SLS (EIM)	DWH Test	DWH 2SLS	LPM	IV 2SLS-(EIM)	DWH Test	DWH 2SLS
1	Cindex	0.0329***(0.0000)	0.0214***(0.0000)	0.0214*** (0.0000)	0.0214*** (0.0000)				0.0329***(0.0000)
2	Age	0.0109***(0.0000)	0.0133*** (0.0000)	0.0133***(0.0000)	0.0133*** (0.0000)	0.0050*** (0.0000)	0.0041** (0.0140)	0.0041**(0.0140)	0.0042*** (0.0010)
3	Edu	0.0106***(0.0000)	0.0118***(0.0000)	0.0118*** (0.0000)	0.0118*** (0.0000)	0.0054**(0.0110)	0.0048** (0.0370)	0.0048** (0.0370)	0.0152*** (0.0000)
4	Hhsize	-0.0173***(0.0010)	-0.0179***(0.0010)	-0.0179***(0.0010)	-0.0179*** (0.0000)	-0.0053(0.1780)	-0.0043 (0.3030)	-0.0043 (0.3030)	-0.1394*** (0.0000)
5	Farmexp	-0.0392***(0.0000)	-0.0447*** (0.0000)	-0.0447***(0.0000)	-0.0447***(0.0000)	-0.0257***(0.0000)	-0.0236*** 0.0000)	-0.0236***(0.0000)	-0.4083*** (0.0000)
6	Extser	-0.0160(0.4800)	-0.0121 (0.0593)	-0.0121 (0.5930)	-0.0121(0.5890)	0.0015 (0.9320)	0.0019 (0.9100)	0.0019(0.9100)	-0.0436* (0.0570)
7	Constant	0.7369*** (0.0000)	0.7157*** (0.0000)	0.7157*** (0.0000)	0.7157***(0.0000)	-0.0578(0.3570)	-0.1103 (0.1300)	-0.1103(0.1300)	1.5518***(0.0000)
8	Lntotprod					0.2380***(0.0000)	0.2550*** (0.0000)	0.2550***(0.0000)	
9	(vhat) ρ				0.0238*** (0.0010)				0.1955***(0.0000)
10	*F-stat*	329.48***				618.95***	3290.34 ***	3290.34***	292.17***
11	*Prob> F*	0.0000				0.0000	0.0000	0.0000	0.0000
12	*Wald (chi2 (6))*		1915.12***	1915.12***				3290.34	
13	*Prob > chi2*		(0.0000)	(0.0000)				0.0000	
14	R^2	0.7431	0.7361	0.7361		0.8472	0.8464	0.8464	0.7425
15	Score chi2(1)			12.4551***(0.0004)				1.1376(0.0862)	
16	Vhat F-test				11.12***(0.0009)				157.66(0.0000)

Figures in parenthesis are p-values. The signs ***, **, & *, represents 1%, 5% & 10% significant levels respectively.

productivity are endogenous in the tenure security model. This confirms the results obtained in the previous sections.

CONCLUSION AND RECOMMENDATIONS

Simultaneous equation models (SEM) have been widely applied in the literature to model the relationship between farm investment and productivity given that investors (farmers) have the potential to obtain credit under secure property rights. The assumption is that the availability of financial credit provides leverage for farmers to increase farm investment in order to optimise farm productivity. The theoretical implication for the use of SEM in this regard is that there might be a potential causal influence amongst the variables: tenure security (enhanced by secure property rights), farm investments, and farm productivity, which is due to endogeneity amongst the variables. Hence, a single-equation method such as the OLS method will not be appropriate because of a potential estimator inefficiency and inconsistency. Analysts have often modelled the SEM without explicitly accounting for endogeneity in the regressors, which might result in mixed results.

This study explicitly determines whether there is a causal influence amongst the decisions to apply for leasehold, increased farm investment, and total productivity on livestock farms in the Kavango West region of Namibia. Using a survey of 510 farms, the results show that the availability of secure tenure rights influences farmers' investment decisions. The summary statistics show that private farmers who have leasehold rights have access to credit and greater fixed farm investments than communal farmers do. This has resulted in higher productivity amongst private farmers than communal farmers. The result is consistent with the regression analysis. A test of endogeneity of tenure security, investment, and farm productivity shows that tenure security is exogenous to farm investment decisions and farm

Table 7. Productivity model: endogeneity test for investment and tenure security in a productivity model.

S/N	Regressors	Endogeneity tests: Investment				Endogeneity tests: tenure security				
		OLS	IV 2SLS (EIM)	DWH Test	DWH 2SLS	OLS	IV 2SLS (EIM)	DWH Test	DWH 2SLS	TEM
1	Cindex	0.1069*** (0.0000)	0.0945*** (0.0000)	0.0945 (0.0000)	0.0591*** (0.0000)					
2	Age	0.0316*** (0.0000)	0.0342*** (0.0000)	0.0342 (0.0000)	0.0415*** (0.0000)	0.0156*** (0.0000)	0.0189***(0.0000)	0.0189***(0.0000)	0.2453 (0.2586)	0.3855***(0.0000)
3	Edu	0.0251*** (0.0000)	0.0263*** (0.0000)	0.0263 (0.0000)	0.0300*** (0.0000)	0.0060 (0.3190)	0.0086 (0.1530)	0.0086 (0.1530)	0.0189*** (0.0044)	0.1081* (0.0620)
4	Hhsize	-0.0523*** 0.0010)	-0.0530*** (0.0010)	-0.0530 (0.0010)	-0.0549*** (0.0000)	-0.0170 (0.1960)	-0.0206 (0.1080)	-0.0206 (0.1080)	0.0086*** (0.0062)	-0.3020** 0.0320)
5	Farmexp	-0.0719*** 0.0000)	-0.0778*** (0.0000)	-0.0778 (0.0000)	-0.0946*** (0.0067)	-0.0047 (0.5620)	-0.0151 (0.2010)	-0.0151 (0.2010)	-0.0206*(0.0127)	-0.8467*** 0.0000)
6	Extser	-0.0630 (0.3420)	-0.0588 (0.3720)	-0.0588 (0.3720)	-0.0470 (0.3870)	-0.0164(0.7500)	-0.0174 (0.7340)	-0.0174 (0.7340)	-0.0151**(0.0118)	-0.2067(0.6090)
7	Constant	3.2812*** (0.0000)	3.2585*** (0.0000)	3.2585 (0.0000)	3.1941*** (0.0000)	1.6310*** (0.0000)	1.7584*** 0.0000)	1.7584*** 0.0000)	-0.0174* (0.0515)	0.3867(0.7590)
8	Tsecurity					2.1504*** (0.0000)	1.9621*** 0.0000)	1.9621***(0.0000)	1.9621 (0.1962)	
9	leasep									11.9170 2482.34)
10	(vhat) ρ				1.8852*** (0.0000)				0.2453 (0.2025)	
11	*F-stat*	135.68***			260.11***	321.7***			276.48***	
12	*Prob> F*	0.0000			0.0000	0.0000			0.0000	
13	*Wald (chi2)*		698.71***	698.71	260.11***		1041.11***	1041.11***		1707.78***
14	*Prob > chi2*		(0.0000)	(0.0000)	(0.0000)		(0.0000)	(0.0000)		0.0000
15	R^2	0.6454	0.6442	0.6442	0.7620	0.7813	0.7795	0.7795	0.7818	
16	Score chi2(1)			1.5961(0.2065)				0.9159(0.3385)	0.90(0.3433)	
17	vhat F-test				163.90***(0.0000)					
18	LR chi2									1.22(0.2690)

Figures in parenthesis are p-values. The signs ***, **, & *, represents 1%, 5% & 10% significant levels respectively.

productivity, whereas farm investment decisions were found to be exogenous to farm productivity. Farmers make more investment decisions when they hold a more secure tenure right, which enhances their productivity on the farm. Overall, there was no evidence to support reverse causality in any of the tests.

Based on the findings of this study, it is recommended that, to achieve increased agricultural production, there should be a strong tenure security and more leasehold land allocation to the farmers in the communal areas. The allocation of land rights under resettlement programme should not solicit for CLRA provision to encourage farmers to apply. This is because it is alleged that resettled farmers are deemed to have benefited thus stand less chance of more land allocation. Other incentives such as financial credit and comprehensive agricultural support are required to assist farmers in acquiring farm infrastructures.

Training and information for the delivery of the land tenure system is not always available to farmers in the rural areas; besides there is a threat of conflict with the traditional institutions. This has resulted in skewed distribution to the privileged elites. Institutional sector should not be completely alienated in the land reform system. This is because, it is alleged that CLRA has obliterated the obligations of the traditional authority by the appointment of Land Board as the main custodian of the land reform programme. Therefore, it is recommended that the effects of information, training and the integration of institutions on the delivery of Land Reform Programme and the impact on tenure security,

Table 8. Discrete dependent variable model: Investment and productivity endogeneity test in a tenure security model.

S/N	Dependent variable : (T security)	Probit		IV-Probit		IV-Probit 2steps	
1	Regressors	Investment	Productivity	Investment	Productivity	Investment	Productivity
2	Cindex	0.4188*** 0.0000)		0.2483***(0.0010)		0.2790*** (0.0010)	
3	Age	0.1046*** 0.0000)	0.1485 (0.1770)	0.1149*** (0.0000)	0.0545 (0.5000)	0.1291*** (0.0.000)	0.0751(0.4810)
4	Edu	0.1369***(0.0000)	-0.0181 (0.6460)	0.1394***(0.0000)	-0.0434(0.1610)	0.1566*** (0.0000)	-0.0598 (0.5140)
5	Hhsize	-0.0450(0.5220)	0.0706 (0.3330)	-0.0644(0.3410)	0.0892 (0.1260)	-0.0724 (0.3380)	0.1231(0.4420)
6	Farmexp	-0.3428***(0.0000)	-0.4668**(0.0270)	-0.3595***(0.0000)	-0.2636(0.1060)	-0.4040***(0.0000)	-0.3638 *(0.0710)
7	Extser	-0.1971 (0.5040)	0.2232(0.6150)	-0.2153(0.4350)	0.1964 (0.5390)	-0.2419 (0.4280)	0.2710(0.7480)
8	Constant	1.8813**(0.0140)	-15.1687***(0.0010)	1.5447**(0.0300)	-13.9301***(0.0000)	1.7359**(0.0430)	-19.2224***(0.0050)
9	lntotprod		5.6687***(0.0000)		5.2860***(0.0000)		7.2942***(0.0030)
10	Diagnostics:						
11	Wald Test:						
12	*Wald (chi2 (6))*	103.03***	32.5***	92.76***		68.88***	11.47*
13	*Prob > chi2*	0.0000	0.0000	0.0000		0.0000	0.0750
14	*Pseudo R2*	0.8566	0.9712				
15	Marginal effect:	0.0774***(0.0000)	0.1534(0.6950)	0.2483 ***(0.0010)	5.2860 ***(0.0000)	0.2790 *(0.0850)	7.2942*** (0.0030)
16	Endogeneity Test:						
17	Wald chi2 (1)			12.16***	9.46	4.39**	2.00
18	Prob > chi2			0.0005	0.0210	0.0361	0.0569
19	Rho			0.4926***(0.0000)	-0.8462*** (0.002)		

Figures in parenthesis are p-values. The signs ***, **, & *, represents 1, 5 and 10% significant levels respectively.

Investment and productivity be investigated in further research.

CONFLICT OF INTERESTS

The authors do not have declared any conflict of interests.

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