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Modelling Grain Surplus/Deficit in Cameroon for 2030

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Abstract

Central Africa has the lowest food production per capita, slow yield development and the fastest growing population in the world. This study aimed to develop a model which estimates the grain surplus or deficit in Cameroon for 2015-2030. Grains form the main diet in Cameroon and the modelled grains in this project are sorghum, millet, rice and maize. Additionally, in the case of a deficit, the yield growth needed to meet consumption in 2030 was calculated and interviews were conducted with farmers in Cameroon. The model results show that a deficit for maize and rice is expected in 2030 but not for millet and sorghum. Yield growth needed for rice is high whereas the maize yield growth needed is smaller. Main identified problems for further production growth are climate change, population growth, postharvest losses and the access to resources such as fertilizers, mechanization, and preservation technology.

Table of Contents

Abbreviations

APHLIS – African Postharvest Losses Information System

DSDSR – Strategy Document for the Development of the Rural Sector

ERS – Economic Research Service

FAO – Food and Agriculture Organization of the United Nations

FAS – Foreign Agricultural Service

FSA – Farm Service Agency

G – gram

ha – hectare

IFAD – International Fund for Agricultural Development

IPCC – Intergovernmental Panel on Climate Change

IRA – Institut de Recherche Agronomique (Institute of Agricultural Research)

Kcal – kilocalorie

Kg – kilogram

mg – milligram

mm – millimeter

PRSP – Poverty Reduction Strategy Paper

psd – Production, supply and distribution

SDG – Sustainable Development Goals

SSA – Sub Saharan Africa

t – tonne

UN – United Nations

UNFCCC – United Nations Framework Conventions on Climate Change

UNVDA – The Upper Noun Valley Development Authority

USDA – United States Department of Agriculture

WFP – World Food Programme

WHO – World Health Organization

Chapter 1 Introduction

Meeting food demand worldwide will become more challenging with a growing population, growing demand, and less available land (Kidane et al. 2006). During the UN conference on Sustainable Development (RIO 20+) in 2012 in Brazil, member states of the UN decided on a list of Sustainable Development Goals (SDGs), which are a follow up of the Millenium Development Goals (UN 2015; Sachs 2012). Goal 2 of the SDGs is to “End hunger, achieve food security and improved nutrition and promote sustainable agriculture” (UN 2015). Targets have been set to reach this goal by 2030 but the progress differs per region and food security can be defined in several manners. According to De Schutter (2012) food security has three aspects including availability, accessibility, and adequacy. This would suggest there must be enough food produced which people are able to access (logistically or economically) and this food must have adequate nutrition and quality for the people to survive.

Food security is especially challenging in Sub-Saharan Africa (SSA), which has lowest production per capita, lowest yield per hectare and one of the fastest growing populations (Kidane et al. 2006). Sub Saharan Africa is defined as all countries south of the Saharan desert on the African continent. The main strategy for dealing with growing demand and declining soil fertility is to expand the cultivation land area (Demeke et al. 2013; Funk & Brown 2009, Shapouri et al. 2009). If the focus for increasing production will remain on cultivation area expansion instead of yield per hectare increase, the production per capita will decrease in SSA (Funk & Brown 2009). One of the main sources of food supply in SSA is domestic production of agricultural products, which is suggested to improve food security (Demeke et al. 2013; Funk & Brown 2009, Shapouri et al. 2009). Another report by the FAO (2003), which assesses the worldwide prospects for agriculture till 2015 and till 2030, concludes that local production in developing countries, where agriculture is the main source of income and employment, play the most important role in improving food security. Most SSA countries, which would classify as developing countries where agriculture is a main source of income and employment, need to import a significant amount of food to meet food demand, thereby building up a large debt (Demeke et al. 2013). Additionally postharvest losses have been mentioned as a big problem (Affognon et al 2015). On the first World Food Conference in 1974 the aim was to reduce postharvest loss rate by 50% in 1985, which was unfortunately not achieved (World Food Conference Rome 1975; Affognon et al. 2015). Clay (2011) suggests that the goal for Africa should be to cut postharvest losses by half by 2030.

Cereals, roots and tubers together formed 54% of the dietary energy supply in Cameroon over the time period 2009-2011 (FAOSTAT 2016). 24% of the cereal consumption in SSA had to be imported in 2006 and half of the cereal import consists out of wheat and a third of rice (Kidane et al. 2006). Maize was exported in the 60s but formed about 15 % of the imports in 2006 (Kidane et al. 2006). Net cereal imports for SSA were predicted to triple by 2030 compared to 2003 according to “The world agriculture: towards 2015/2030” report by the FAO (2003). The cereal aid shipment to Cameroon was 11,135 tonnes in 2015 and the cereal import dependency ratio for 2009-2011 was 25.8% (FAOSTAT 2016). The import dependency ratio is defined by the following equation:

$$1)\ IDR = \left(\frac{Imports}{Production + Imports - Exports}\right) * 100$$

Additionally Funk & Brown (2009) suggest that Central Africa (including Cameroon, Angola, Central African Republic, Chad, the Republic of Congo, the Democratic Republic of the Congo, Equatorial Guine, Gabon, and São Tomé and Principe) has the lowest production per capita (62 kg per person per year) on the African continent for 1980-2007. This together with the suggestion that Central Africa has a slow yield development and the difficulty of making predictions due to a lack of data for this particular region suggests that Cameroon will be challenged to match its cereal production to the consumption (Funk & Brown 2009).

1.1 Aim and Hypothesis

This research project aims to estimate the crop availability defined as estimated domestic consumption and postharvest loss subtracted from the estimated domestic production of maize, rice, sorghum and millet for the 2015-2030 period in Cameroon. Additionally if the consumption and postharvest loss is higher than the production per year, which results in a crop deficit, the aim of this research is to analyze how much the yield per hectare has to increase to meet consumption in 2030.

The null hypothesis is that the crop surplus/deficit does not differ between 2015 and 2030. The alternative hypothesis is that the crop surplus/deficit based does differ between 2015 and 2030. It is expected that the null hypothesis will be rejected and that crop availability in 2030 will differ from the crop availability in 2015. Based on the literature suggestions, and cereal aid shipment data FAOSTAT database (2016) it is expected that the difference will be a crop deficit for all four grains in 2015 and in 2030. This suggests that yield or cultivation area has to increase in order to raise the production to meet the consumption in 2030.

Chapter 2 Background

2.1 Food security

2.1.1 Definitions

In 1975 the definition of food security by the United Nations concentrated on the production of food on different levels (Clover 2010). The main focus was on gathering food balance sheets, which indicate how many calories are produced and consumed (Jones et al. 2013). In the 1980s the discussion focused on the issue that available food does not equal the actual consumption of food and the food people can access (Jones et al. 2013; Barrett 2010). It was pointed out that the access and the ability to get food on household level play an important role (Clover 2010; Barrett 2010). Therefore the 1974 definition was altered to include the access to food both economically and physically (Jones et al. 2013). Subsequently, in the 90s the discussing shifted to the actual nutrients in food and under nutrition in terms of lack of vitamins and micronutrients (Jones et al. 2013; Barrett 2010). Including these factors led to a definition of food security, which concentrated on the individual level and included the actual utilization of the food that was produced and accessed (Jones et al. 2013; Barrett 2010). Eventually in 1996 the Rome Declaration on World Food Security described food security as : *"Food security, at the individual, household, national, regional and global levels [is achieved] when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life"* (FAO 1996). This definition includes availability, accessibility, and utilization (Jones et al. 2013). This is similar to De Schutter's definition although utilization replaces what De Schutter names adequacy (2012). The fourth factor discussed in the Rome Declaration definition and indicated with *'at all times'* is the duration in time one of the factors defining food security is lacking. Food insecurity is sometimes perceived as the lack of one of the factors defining food security for a longer time but the inclusion of *'at all times'* suggests the lack of these aspects at any moment would be food insecurity (Jones et al. 2013). Production, consumption and nutrition values of foods are used by the FAO to monitor and project food security (Jones et al. 2013). It should be noted however that for projections this definition assumes the average calories consumed by society is the same for all income groups, while in reality accessibility and distribution might differ.

According to Clover (2010), food security nowadays consists out of several complex associated factors including economic, social and political situations. This explanation makes the assessment of SSA food security challenging when including weather related catastrophes, HIV/aids and the political and economic situations (Clover 2010). The Rome Declaration definition includes the term accessibility indicating the inclusion of the previously mentioned interrelated factors (Barrett 2010). This makes the measurements of food security more difficult as compared to using only availability (Barrett 2010). Accessibility, which includes physical and economic access, is often determined by and used synonymously with food consumption (Jones et al. 2013). Food consumption over time implies the available food that can be accessed during a period and includes therefore three of the four factors of food security. It is important to note that sufficient consumption does not mean the access to food is high (Jones et al. 2013). The food consumed might still take substantial effort to access. Different definitions and measurements used for defining food security such as the food balance sheet (undernourishment levels) or production/consumption ratios, lead to very different results by organizations such as the FAO and USDA (Barrett 2010). These various challenges include nutrient adequacy definitions, distinguishing food access factors, and validation of the large range of measurement and definition methods (Jones et al. 2013).

2.1.2 Yield Gap

In SSA the main method of increasing the production of crops is to expand the cultivation area (Funk & Brown 2009; Shapouri et al. 2009; Demeke et al. 2013). For the last decades almost 90 percent of crop production increase was due to cultivation area enlargement (Shapouri et al. 2009). The yields per hectare in SSA are only one third of the global mean and are the lowest on the global yield per hectare ranking (Shapouri et al. 2009). Another method for production growth would be to increase the yield per hectare and narrow the yield gap. The yield gap is defined as the difference between the potential yield and the actual yield (Van Ittersum et al. 2013). The potential yield is the yield when a crop grows without water and nutrient limitations and no biotical stressed environment (Van Ittersum et al. 2013). Potential yield is therefore only controlled by CO_2 levels, temperature, solar energy, individual plant genetics and dependent on the climatic environment (Van Ittersum et al. 2013). Yield gap decrease could lead to a production increase, which could enhance the domestic production and positively affect the food security in these regions. The yield gap could be decreased by reducing the water and nutrient limitations through the use of fertilizers or irrigation.

2.2 Nutrition

The Green revolution was a period in the 60s and 70s in which a combination of introducing hybrid strains of cereals and new technology increased the overall production per hectare, especially in developing countries (Khush 2001). This also led to a shift from region traditional crops such as millet and sorghum to an increased the maize monoculture (Clover 2010). Overall the calorie consumption in SSA has risen between 1990 and 2009 (FAO, WFP and IFAD 2012). However, SSA still has the lowest consumption in the world (FAO, WFP and IFAD 2012). Additionally in SSA the cereal part of the diet increased forming 1000kcal of the 2250kcal total consumption (FAO, WFP and IFAD 2012). The share of carbohydrates from cereals becomes more important and grows when the household has a lower income whereas a higher income leads to a higher fat consumption (FAO, WFP and IFAD 2012). Grains form therefore one of the main nutrition providing components for low income countries, regions and households.

The utilization part of food security indicates that the consumed food also needs to provide enough nutrition for an individual to function (Barrett 2010). This concerns the quality of the crops but also the vitamins and minerals present in the diet. Barrett (2010) suggested that at least 2 billion people are affected by shortages in micronutrients such as iodine, zinc, iron and vitamin A, especially women and infants. Cereals form a big part of the diet and mainly provide energy but in order to have food security the diet should consist out of more food types, which include the whole spectrum of vitamins, minerals, fat, and protein. The FAO data suggests 30.6% of the population of Cameroon had a vitamin A deficiency in 2005 (FAOSTAT 2016). Furthermore there is data for iodine deficiency in 1993 available which applied to 91.7 % of the population in Cameroon (FAOSTAT 2016). This suggests the utilization part of food security in Cameroon is not fulfilled for a large part of the population. Table 1 shows the different nutritional values of the grains discussed in this paper and implies that there are only slight differences in carbohydrates and calories. There are however considerable differences in the protein, calcium, fat and iron values per 100 gram. Adults between 19 and 50 would need a 1000 mg of calcium per day, 8 mg iron per day for men and 18 mg iron for women (NIH 2013). Men need around 2500 kcal per day and women 2000 kcal, which can be retrieved from protein, fats and carbohydrates (NHS 2014). Proteins play an important role in human nutrition and the recommended intake by the NIH dietary reference intake is 0.8g per kg of body mass per day for adults (Food and Nutrition Board 2005).

Table 1 Nutritional values of the four selected crops per 100g. This table is based on a table by the FAO in Sorghum and millets in human nutrition 1995.

Crop	Protein (g)	Fat (g)	Carbohydrates (g)	Calories (kcal)	Calcium (mg)	Iron (mg)
Rice	7.9	2.7	76	362	33	1.8
Maize	9.2	4.6	73	358	26	2.7
Sorghum	10.4	3.1	70.7	329	25	5.4
Millet (common)	12.5	3.5	63.2	364	8	2.9

2.3 Study Area

The republic of Cameroon is located in Central Africa between Equatorial Guinea, Gabon, Congo, West of Nigeria and East of the Central African Republic and Chad (8-16E; 1-13 N) (Figure 1) (Pamo 2008). The country area is 475,440 km^2 of which 97,500km^2 is agricultural and 192,560 km^2 is forest area (FAOSTAT 2013). Before the Germans claimed Cameroon, the country was not defined with the current borders and as one country (Pamo 2008). After the first world war Cameroon was taken from the Germans and divided between the French (East Cameroon) and the English (West Cameroon) in 1916 (Pamo 2008). In 1972 French-Cameroon and English-Cameroon were merged but both languages remain the official languages. Cameroon has 10 provinces, which are further divided in divisions, sub divisions and districts, and around

204 ethnic groups are present (Pamo 2008). The total population of Cameroon was 23,344,180 in 2015 (FAOSTAT 2016).

Agriculture is one of the most important sectors of Cameroon's economy, with 70% of the labour force active in the agricultural sector (Molua 2008). According to Achancho (2013), Cameroon's agricultural policy can be divided into four periods: "The five-year development plans period" between 1960 and 1986, "The beginning of the economic crisis period" between 1986 and 1990, "The new agricultural policy" between 1990 and 1998 and "Agricultural Policy- New challenges" from 1999. In the first phase, which was established after the independence, the aim was to develop a five year plan for every five years (Achancho 2013). The focus was on increasing exports, cultivating of industrial crops, promoting rice and wheat production to replace imports (Achancho 2013). During this period the state subsidized the agricultural sector and guaranteed prices (Achancho 2013). At the end of this period and the start of "the beginning of the economic crisis period", development money was shifted to infrastructure and agencies, and oil production started (Achancho 2013; Pamo 2008). The economic crisis led to a GDP and export decrease whereas the debts increased. The state became aware of the importance of agriculture to the economy and food security of the country. To improve the agricultural sector the "New Agricultural Policy (NAP)" was developed, which led to the "new agricultural policy period" (Achancho 2013). The priorities of this policy were to improve the production means and food safety, encourage exports and expand the export products range, enhance the processing of agricultural commodities, and to stabilize supplies (Achancho 2013). The results were lower than expected due to internal market disruptions, lack of private funding and institutional foundation (Achancho 2013). Therefore the last period "Agricultural Policy – New Challenges" focused on the agricultural organizations, production and income increase, and the agricultural sector as backbone of Cameroon's economic and social development (Achancho 2013).

Cameroon has very diverse climate environments and land covers. Temperatures increase from South to North, from the coast to inland areas and from low altitudes to higher altitudes (Pamo 2008). The mean annual temperature for the South is 25 degrees Celsius whereas in the North daily temperatures range between 25 to 34 degrees Celsius (Pamo 2008; Molua and Lambi 2007). The daily average temperature diminishes with higher latitude (South direction) and altitude (Molua and Lambi 2007). The southern humid equatorial area and the northern semi-arid area bordering to the Sahel are the two main climatic environments (Molua and Lambi 2007). The average rainfall per year in the humid equatorial area is around 1500mm whereas the semi-arid region the mean rainfall is around 500mm (Molua and Lambi 2007). The main seasons are wet and dry. The dry season starts normally in October and dominates for approximately nine months in the North and six months South (Molua and Lambi 2007). The wet season starts around mid-March and lasts longer in the southern part compared to the northern parts (Molua and Lambi 2007). Most rain falls along the coastline between April and October (Molua and Lambi 2007).

The ecosystems present in Cameroon are equatorial forests, including mangrove and rainforests, in the south and coastal lowlands, which gradually turn into tropical grasslands, in Northern Cameroon (Pamo 2008). The grasslands can be divided into Guinea Savanna (north of the tree line and consists out of tall grasses and trees), Sudan Savanna (savanna with small trees and shrubs) and Sahel Savanna (the far north with a long dry season and small patches of grasses) (Pamo 2008).

Regarding Cameroon’s sustainability and climate change policy, the UNFCC convention was signed by Cameroon in 1992 and ratified in 2004 (Bele et al. 2010; Sama and Tawah 2009). Cameroon therefore agreed to contribute to reducing greenhouse gases, which are mainly caused by agricultural activities and land use change (Bele et al. 2010). A law on the environment, which is the foundation for the environmental policies, was accepted in 1996 after the Rio Summit (Bele et al. 2010; Sama and Tawah 2009). At the start of 2000, the millennium development goals (predecessor of the SDG’s) required that Cameroon also focused on the social and economic sustainability factors (Bele et al. 2010). Therefore plans to guarantee agricultural sustainability in order to increase food security, production and decrease poverty were developed in the Strategy Document for the Development of the Rural Sector (DSDSR) and Poverty Reduction Strategy Paper (PRSP) (Bele et al. 2010; PRSP 2003). The only document, in which Cameroon directly addressed the climate change affairs, is the First National Communication to the UNFCCC in 2005 (Bele et al. 2010). The goals in the PRSP however support climate change adaptation and acknowledge that poverty and environmental issues are strongly related (Bele et al. 2010). Currently there are still no specific rules for sustainable development and climate change is not a first concern in the governmental administration (Bele et al. 2010).

Figure 1 Map of Cameroon No. 4227 Rev.2 November 2015 (UN Geospatial Information Section 2015)

Chapter 3 Method

The methods used for this research project consist out of quantitative methods involving system dynamics modeling and qualitative methods including open interviews. The quantitative methods section will first discuss the data used and the input parameters and variables calculated for each section of the model. Subsequently the model development will be discussed, followed by the model sensitivity and validation.

3.1 Quantitative methods

3.1.1 Sources of data and modelling

3.1.1.1 Databases

The parameters and variables for the model were extracted from the USDA psd online (USDA psd online 2016) and FAOSTAT database (FAOSTAT database 2016). The USDA database was used for the cultivation area, yield and consumption data (Table 2) whereas the population data was retrieved from the FAOSTAT database (Table 2). Population data was downloaded from FAOSTAT because the USDA database does not provide population data. USDA psd online provides production, yield, cultivation area, consumption, import, export, and stock data for all countries worldwide. According to the USDA database, *"The USDA database uses official country statistics, reports from agricultural attaches at U.S. embassies, data from international organizations, publications from individual countries, information from traders both inside and outside a country"* (USDA psd online 2016). The FAOSTAT database requires using member countries official statistics when these are available and therefore uses only one source. One of the differences is the use of market years, which normally start around September for the Northern hemisphere and April for the Southern hemisphere, for the USDA database and calendar year for the FAOSTAT database (USDA psd online 2016). The USDA psd online was chosen because it is user friendly, grain data is updated monthly, and the information is based on several sources such as country statistics, embassies, the Foreign Agricultural Service (FAS), the Economic Research Service (ERS), or the Farm Service Agency (FSA). Moreover, the USDA database gives data for 2015 whereas the FAOSTAT database only gives data till 2014. There were no quality flags available for the databases, only an explanation of the data sources.

Table 2 Overview of data downloaded for specific time periods from the USDA or FAOSTAT database.

Data	Database	Years
Cultivation area	USDA psd Online	1990-2015
Yield	USDA psd Online	1990-2015
Consumption	USDA psd Online	2015
Population	FAOSTAT	2015

3.1.1.2 Linear trend calculation

Linear trend calculation was used to calculate the linear trend based on the historical data of the model components (e.g. yield and cultivation area). The historical data is observed data from 1990 till 2015. The linear trends were used to derive the parameters for the model. For this method all historical data was plotted and the trend line equation was determined based on the data plot. The calculated slope value in the linear equation, which was calculated with the least squared method, indicated the slope of the trend line and was used as the trend parameter. Linear trend for all parameters was chosen because of consistency and simplicity purposes. Although not all data plots (Figure 2 and 3) seem linear, it is difficult for the model to use a linear trend calculation for one crop but not for the other. A linear trend can show the average trend over a longer time period and fit into the idea of parsimony and consistency for all crops and parameters. In order to assess the fit of the trends to the real data, R^2 was calculated. The R^2 assesses how well the data fits the trend line (Hawkins 2009). A R^2 of 1 suggest that the fit is optimal, whereas 0 would suggest that there is no association (Hawkins 2009). Additionally a F test was performed to test for significance.

3.1.1.3 Population

One of the submodels is the population model. This submodel requires the current population numbers and the birth and deathrates. The population data is retrieved from the FAOSTAT database (2016). The Bureau Central des Recensements et des Etudes de Population (BUCREP) (Central Office for Census and Population Studies in Cameroon) provided the number of people per age category for 2005 (BUCREP 2006). This data was used to calculate the percentage of the population that belongs to the defined age groups 0-15, 16-30,31-45,46-60 and 61+ (Table 3) . The age groups are 15 years wide because this covers the differences between the age stages but generalizes the groups for model purposes. It was assumed that the percentage of the population in a certain age group approximately represents that age distribution in different years.

Table 3 Age groups used for the population model and the population percentage per age group for 2005 as defined by the Bureau Central des Recensements et des Etudes de Population (BUCREP 2006).

Age group (years)	Percentage of total population
0-15	46.34%
16-30	28.17%
31-45	14.01%
46-60	7.33%
61+	4.15%

The birthrates are based on the number of live births per 1,000 of the population per year and divided by 1,000 to get the rate per person. Birthrates for the age group 16-30, 31-45 and 46-60 were based upon the average birthrate for Cameroon which is 0.04 per person per year for 2005 and 0.037 for 2013 (WorldBank, 2016). Additionally the adolescent birth rate (15-19) according to the World Bank was 0.139 in 2005 and decreased to 0.107 in 2014. Given these adolescent birth rates, the birthrate for the 16-30 age group was set higher compared to the other two age groups. The average of the three birth rates is approximately the national birthrate average for Cameroon (Table 4). It was assumed that the probability of giving birth in the 46-60 age group is very low since the older age decreases the chance of pregnancy for women. The death rates for each age group were based on the national death rate suggested by the World Bank. The death rate for 2005 is 0.014 per person per year and slightly decreases to 0.012 in 2013 (WorldBank). The life expectancy for the Cameroonian population is around 57 years (WHO 2016). Therefore the death rates for the 46-60 and 61+ age group are set higher than the younger age groups (Table 4). The infant mortality rate for Cameroon is 61 per 1000 births, which is higher than the average death rate (Unicef 2013). Consequently the death rate for the 0-15 age group is higher than the 16-30 and 31-45 age groups (Table 4).

Table 4 Parameters and input variables used in the population model

Age group (years)	**Death Rate (per person per year)**	**Birth Rate (live birth per person per year)**	**Initial Population (2015)**
1) 0-15	0.004		10,817,028
2) 16-30	0.002	0.091	6,575,582
3) 31-45	0.002	0.02	3,270,536
4) 46-60	0.009	0.001	1,711,699
5) 61+	0.07		969,335
Total	0.017	0.37	23,344,180

3.1.1.4 Crop Production

The other submodel is the crop production submodel, which defines the production. The crop production submodel requires yield and cultivation area data, which can be seen in Figure 2 and 3. Linear trend calculation was used to calculate the yield and cultivation area parameters per crop (Figure 2 and 3). The calculated parameters can be seen in Table 5 and 6.

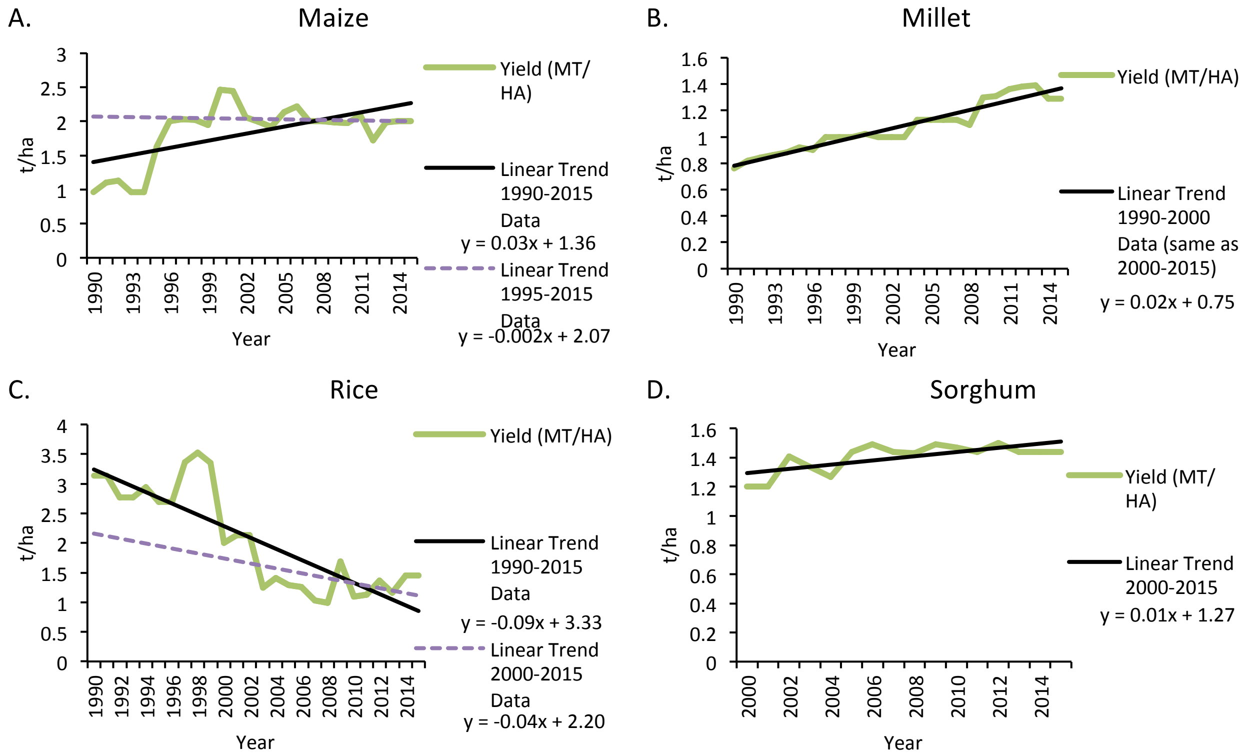

Figure 2 Original yield data and linear trend for studied crops from 1990 and 2000 till 2015. Black line shows the trend from 1990 till 2015, purple dotted trend line shows trend line from 2000 till 2015. Trend values can be seen in the legend.

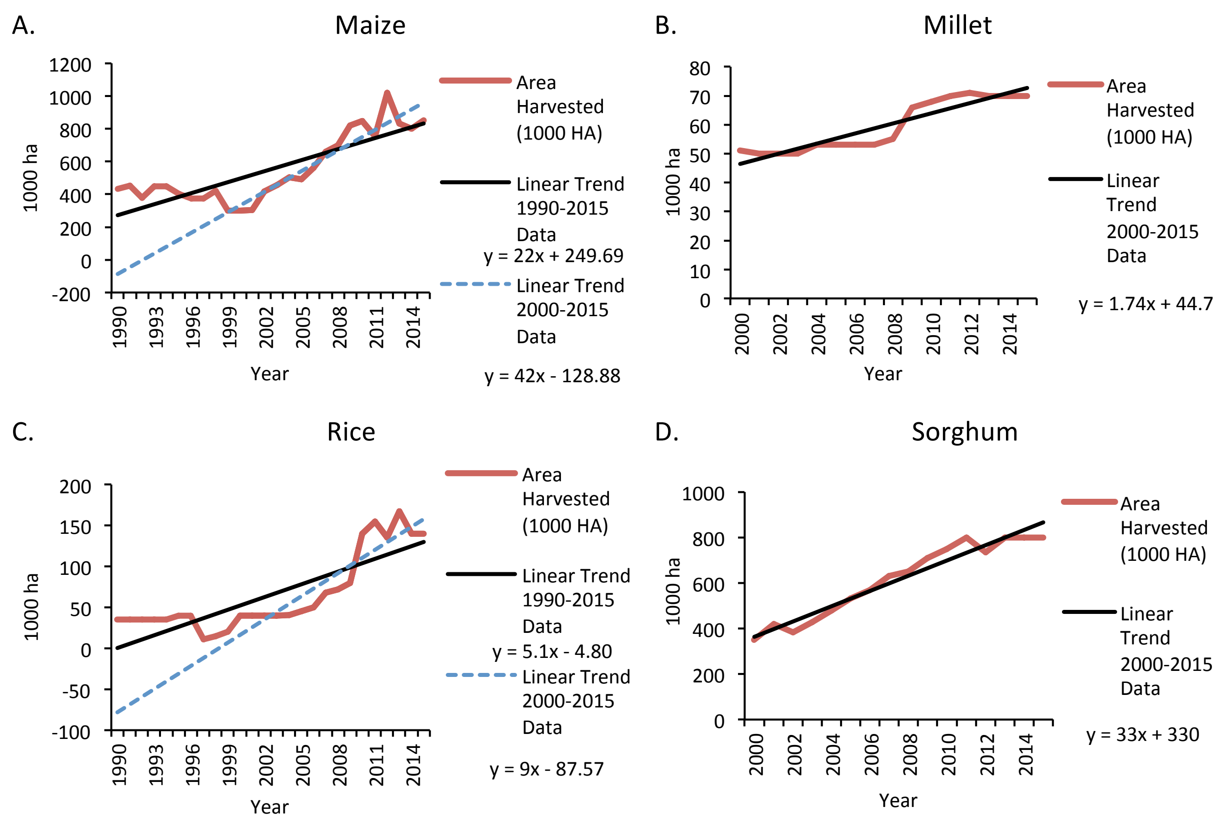

Figure 3 Original cultivation area data and linear trend for studied crops from 1990 and 2000 till 2015. Black line shows 1990-2015 trend line, blue dotted line shows 1995-2015 trend line. Trend values can be seen in the legend**.**

Sorghum yield and cultivation area data was only available from 2000 onwards, therefore the trends for sorghum are based on 2000-2015 data. Since the sorghum data is only available from 2000 the aim was to calculate the trends of the other grains also from 2000. Additionally, the 2000-2015 time period represents a time span of 16 years which is equal to the time span the model attempts to predict (2015-2030). An exception is the maize yield data for which the 1995-2015 period is used because there was a peak in 2000 (Figure 2), which would have led to a more negative yield trend. The rice yield decreased between 1990 and 2003 hence why the trend between 1990 and 2015 is negative (-0.09 t/ha/yr) (Figure 2). Since it is difficult to predict how the trend will continue, the rice yield trend of the same time period 2000-2015 as the other grains is used (-0.04 t/ha/yr) (Figure 2).

The millet yield trend based on the set 2000-2015 timespan was 0.02 t/ha/yr. However the yield model requires the change of the yield growth as an input. In order to have the linear growth of 0.02 t/ha/yr (based on linear trend calculation) for the first years the rate of growth was set to be 0.005. For the rice yield, the same adaptation was needed. The input value needed is the change of the yield growth, therefore a value was chosen which leads to a trend of -0.04 t/ha/yr for the first years (Table 5). The yield parameter did not have to be adapted for sorghum and maize because the calculated parameters already lead to a yield growth according to the linear trend calculation. The yield model for positive yield trends required the maximum potential yield value per crop, which could be found in the literature (Yengoh 2014; Rockström &Falkenmark 2000) (Table 5). For the decreasing trend the lowest occurring yield was used (Table 5).

Table 5 Input parameters, variables and trend values for the yield model. Baseline period shows on which time period the linear trend calculation is based. * indicates that the value is significant with α = 0.05.

Crop	**Yield trend (rate)**	**Baseline period**	**Current yield 2015 (t/ha)**	**R^2**	**Lowest occurring yield (t/ ha)**	**Maximum potential yield (t/ha)**	**Reference for maximum potential yield**
Maize	-0.002	1995-2015	2	0.08	0.96	6.1	(Yengoh 2014)
Millet	0.005	2000-2015	1.29	0.91*	-	5	(Rockström &Falkenmark 2000)
Sorghum	0.01	2000-2015	1.44	0.54*	-	2.3	(Yengoh 2014)
Rice	-0.08	2000-2015	1.45	0.45*	0.99	5.2	(Yengoh 2014)

The R^2 was calculated for the different trend options for yield per hectare per crop. R^2 was not used as the main argument for determining the yield parameter because the trend values are based on the historical data (1990-2015), the model results were compared with. Therefore the R^2 just gives an indication of how well the linear trend value fits the actual data. The adapted yield trend for millet and rice due to the model design was also checked with R^2. When directly using the linear value in the yield model (0.02 t/ha/yr) for millet, the R^2 is 0.9. The corrected 0.005 value leading to a linear trend of 0.02 t/ha/yr for the first years has a R^2 of 0.91. The linear rice yield trend value led to a R^2 of 0.4 whereas the corrected value of -0.08 resulted in a R^2 of 0.45.

For the agricultural area trend the same method was applied based on the USDA 2000-2015 data for cultivation area per specific crop (Figure 3 and Table 6). The maize and rice cultivation area data showed a very different trend for the 1990-2015 and 2000-2015 period (Figure 3). In both cases the model has been run with both trend values to examine the effect of the different trend value period on the model results (Table 6). The current agricultural area was based on the 2015 cultivation area for each crop suggested by the USDA psd online database (Table 6). R^2 was calculated for the cultivation area trends (Table 6) and was treated the same way as the yield per hectare R^2.

Table 6 Cultivation area growth and current cultivation areas used for the cultivation area model. The last column shows the R^2 for each rate cultivation area growth value. If two rate cultivation area growth values are shown, the first value is based on the 1990-2015 period and the second on the 2000-2015 period. * indicates that the value is significant with $\alpha = 0.05$.

Crop	Cultivation area growth (1000 ha yr^{-1})	Current cultivation area 2015 (1000 ha)	R^2
Maize	22 / 42	800	0.65*/0.87*
Millet	1.7	70	0.84*
Sorghum	33	800	0.95*
Rice	5.1/9	140	0.65*/0.82*

3.1.1.5 Crop Consumption

In order to define the total consumption in the model the consumption data per person is needed. The USDA psd online database provided consumption data per year for maize, rice, sorghum and millet. The consumption per person is based on the consumption per crop divided by the total population in 2015. The annual maize consumption per person was 73 kg in 2015, millet consumption was 3.8kg per person, rice consumption 28 kg per person and sorghum consumption 50 kg. The consumption data from USDA, which was used for this model, includes food, feed, industrial and seed consumption (USDA psd database 2016).

3.1.1.6 Postharvest Loss

Postharvest losses are a separate component in the model, which decrease the crop stocks, and are included in this model as a percentage of the production. Postharvest losses are defined as the loss of food after harvesting, thus in between the harvest and the actual consumption of the food (Hodges, Buzby and Bennett 2011). The rate of postharvest loss per crop was based on the data of APHLIS (African Postharvest Losses Information System 2016). The postharvest loss percentages are determined by the latest percentages provided by APHLIS. Table 7 shows the postharvest loss rates used and the year of the provided postharvest loss rate for each crop. APHLIS did not provide data for millet postharvest loss in Cameroon. Therefore the millet postharvest loss rate is based on the average millet postharvest loss for the other SSA countries in 2013, which is the most recent year data is provided for most SSA countries in APHLIS. It has been several times suggested that the aim for Africa should be to reduce postharvest loss by 50% (World Food Conference Rome 1975; Affognon et al. 2015; Clay 2011). Due to new and cheaper technology it could be possible that postharvest losses will decline in the near future. Therefore the postharvest loss rates are considered to start at the rates given in Table 7 and then linearly decrease to half the rate in 2030 for this model.

Table 7 Postharvest loss percentage of the production in Cameroon for maize, rice, sorghum and millet. Baseline year indicates the year for which APHLIS provided the postharvest loss rate which is used in the integrated model.

Crop	**Baseline Year**	**Postharvest Losses (%) from production**
Maize	2013	22
Rice	2010	11.2
Sorghum	2010	12.3
Millet	2013	10

3.1.2 Model development

All the modeling was done in STELLA (isee systems 2016). Submodels were developed first and subsequently connected with each other. This section will discuss the separate submodels and the integrated final model. The above discussed parameters and variables are used as input in these model components.

3.1.2.1 Population model

The conceptual population model consists out of five stocks representing the five age groups (Figure 4). Starting with the births the model moves the different age groups through each stock, which represents 15 years. Thus after 15 years a birth count will have moved on to age group 2. All five age groups together form the total population. The births are determined by a birth rate for age group 2 (16 to 30), age group 3 (31 to 45) and age group 4 (46 to 60), which together form the total births for the total population (Table 4). The birthrates are numbered according to the age group (i.e. birthrate 2 is the birthrate for age group 2). Every year (model cycle, time step) the total births will start in age group 1. The outflow of the population model is the total deaths. The total deaths consist of the sum of the deaths in each age group and are calculated by the death rate per age group (Table 4). Before the model moves the different age groups to the next age groups the deaths are subtracted for each age group. For each year the populations of the age groups were summed up and this was assigned as being the total population.

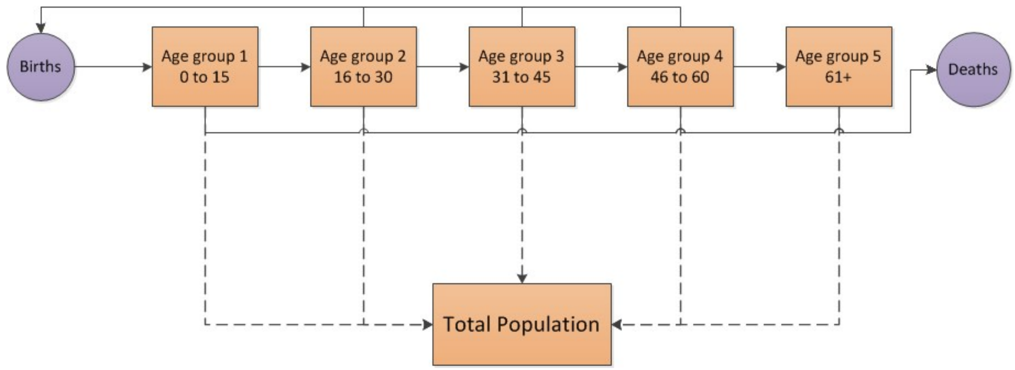

Figure 4 Population model outline with five age groups stocks represented in rectangles. The inflows and outflows of births and deaths are represented by the circles and arrows. In the model each arrow has a parameter assigned according to Table 4. The total population is calculated by taking the sum of the five age group stocks, as shown by the dashed line.

3.1.2.2 Crop Production model

The crop production model includes the yield per hectare model and cultivation area model (Figure 5). The yield per hectare model is determined by the current yield per hectare, the yield trend value and the maximum potential yield or lowest occurring yield value of the specific crop (Table 5). Since yield is eventually limited, the maximum potential yield value is included in the current yield per hectare calculation and forms an asymptote.

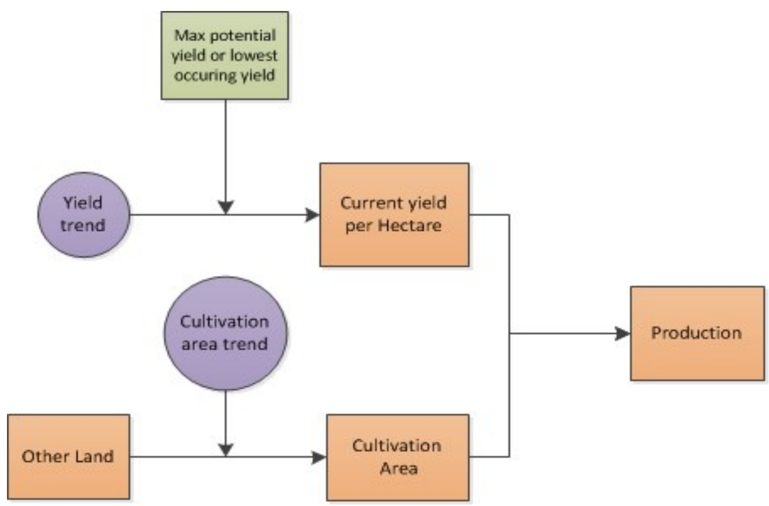

Figure 5 Crop production model consisting of a yield model and cultivation area submodel. Circles indicate parameters according to Table 5 and 6. The initial values for the stocks are also shown in Table 5 and 6. The green rectangle is a set maximum potential yield or lowest occurring yield value which the yield per hectare cannot exceed.

The actual yield change (t/ha), which is added or subtracted to the current yield each year, is determined by the following equation:

$$2)\ \text{Yield change} = \text{Yield trend} * (\text{max potential yield} - \text{current yield per hectare})$$

Where yield trend is the calculated trend, max potential yield is the yield per hectare, which cannot be exceeded and the current yield per hectare is the yield per hectare in 2015.

Rice and maize have a negative yield trend based on the historical data in which case the asymptote is set by the lowest occurred yield per hectare in the available data (1990-2015). It is assumed the yield will not be lower than this number because a yield of zero is no yield and therefore not realistic. The equation for the negative yield trend is:

$$3)\text{Yield change } = \text{Yield trend} * (\text{current yield per hectare} - \text{lowest occuring yield})$$

As the yield per hectare increases, the difference between the current yield and max potential yield becomes smaller and thus the yield change will also become smaller over time. In the case of the increasing yield the model adds the yield change to the current yield per hectare. When the yield is decreasing, the model subtracts the yield change from the current yield. This submodel is therefore not linear. However, the parameters used for the yield model are based on a linear trend analysis of the historical data from 2000-2015 or 1995-2015 in the case of maize (Figure 2). In order to use these trends for this submodel, the yield trend value were chosen in such a manner that the first years the yield change is similar to the calculated linear trend. This means that the values for rice and millet had to be adjusted as mentioned in the data description. After the first couple of years with the calculated trend value, the yield change alternates according to the graphical function and the influence of the max potential yield or lowest occurring yield.

The cultivation area model is defined by the current cultivation area per crop and the cultivation area trend. Since the total land area of the country is fixed (475,440 km^2), the cultivation area trend is subtracted from the land that is not agricultural area and added to the cultivation area in hectares. The total land area is therefore an upper limit. The production is the yield per hectare multiplied by the cultivation area per crop (Figure 5).

3.1.2.3 Consumption, postharvest loss and model connections

The yield multiplied by the cultivation area forms the production, which is the input for the crop available stock. The postharvest loss is calculated as a percentage of the production and then subtracted from the crop available (production). The postharvest loss percentage is set to decrease linearly over time (per year). Lastly the consumption is subtracted from the crop available stock and is calculated by multiplying the consumption per person with the total population. This results in the surplus or deficit per grain for Cameroon for each year up to 2030. Equation 4, 5 and 6 show these calculations. Figure 6 shows the different model components and their connection.

$$4)\text{Postharvest loss} = \text{Postharvest loss percentage} * \text{production}$$

$$5)\text{Total Consumption} = \text{Total Population} * \text{Consumption per person}$$

$$6)\text{ Crop Available} = \text{Production} - \text{Postharvest loss} - \text{Total Consumption}$$

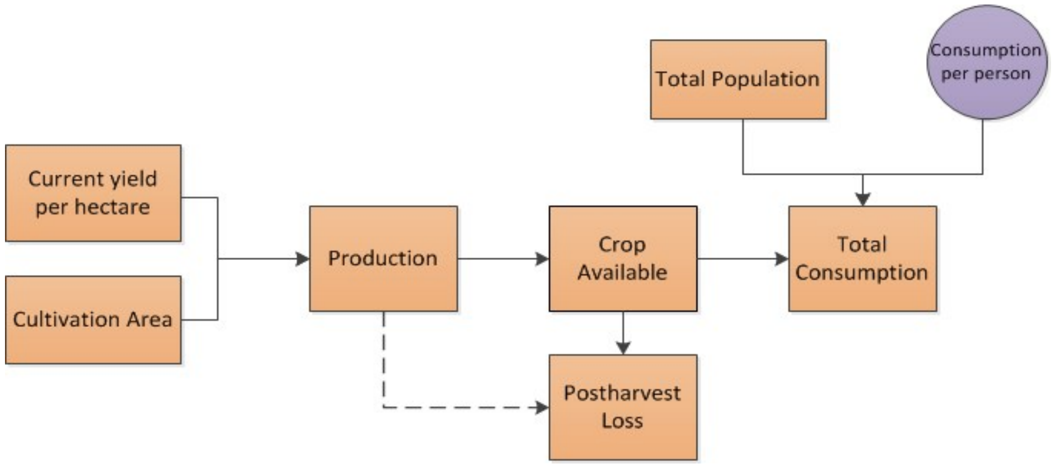

Figure 6 Final steps in the integrated model including the production as an inflow, and postharvest loss and total consumption as outflow. Postharvest loss is a percentage of the production, indicated with the dashed line.

3.1.2.4 Model Assumptions

The integrated model predicts the production, consumption and postharvest loss for maize, sorghum, rice and millet in Cameroon. It assumes that the linear trend of historical data for yield, cultivation area, and population from +/- 2000 till 2015 will be similar to the average trend from 2015 till 2030 including the occurring outliers and nonlinear trends. Therefore it is assumed that outliers in the past reflect outliers in the future 15 years. These outliers include years of extreme climatic events or bad agricultural years. Additionally the model assumes that the cultivation area increases linearly, whereas the yield per hectare change diminishes as the yield gets closer to the asymptote (the max potential yield or lowest occurring yield). The model only includes yield per hectare, cultivation area and postharvest losses as determinants of the production. The per capita consumption is fixed (2015 baseline) and therefore the total population determines the growth of the consumption each year.

3.1.3 Model Sensitivity

The model was run with a change in one of the parameters of plus or minus 10 % or 20% to assess the sensitivity of the model. The aim was to examine the difference in the results caused by a change in the parameter. The most sensitive parameter will already lead to differences in the results at a 20% change. A further change to for example 50% was therefore not necessary. The sensitivity results for maize with 22,000 ha yr^{-1} cultivation area trend and 42,000ha yr^{-1} cultivation area trend are shown in Figure 7 and 8. The other sensitivity graphs can be found in appendix 8.2. In both cases the figures show that the model is most sensitive to the cultivation area trend and birthrate 2, which is the birthrate for the age group 2 (16-30 years). The model is furthermore most sensitive to birth rate 3 (age group 3, 31-45 years), final death rate (age group 5, 61+ years) and yield (Figure 7 and 8). This is similar for all the different grains, although the position of these three parameters differs. The other parameters have similar low sensitivity (Figure 7 and 8).

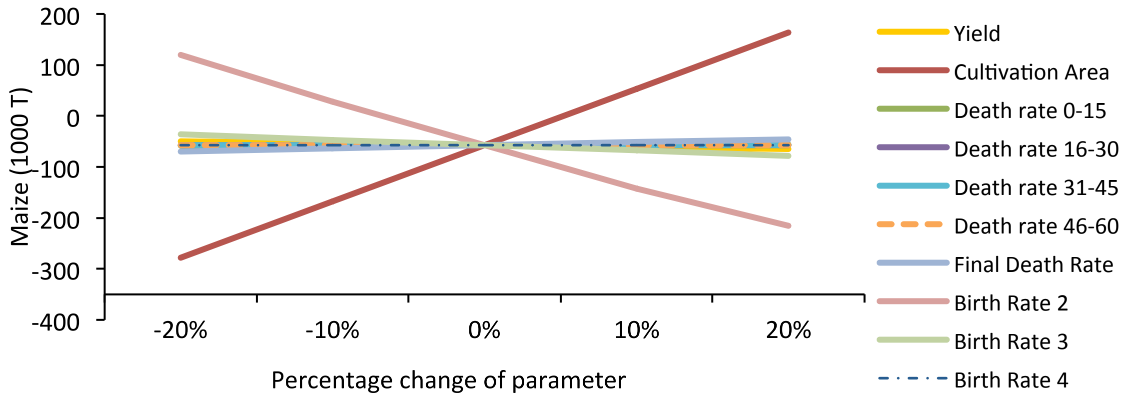

Figure 7 Sensitivity graph for maize with a cultivation area trend value of 42,000ha yr^{-1}. X-axis shows percentage change of the parameter and the y-axis shows the results in maize crop surplus/deficit. The death rate for the 0-15, 16-30, 31-45,46-60 age cohorts and birth rate 4 (age group 46-60) have overlaying lines at the same trend. Deathrate for age group 31-45 and 46-60 lines in the graph show the trend for all these groups.

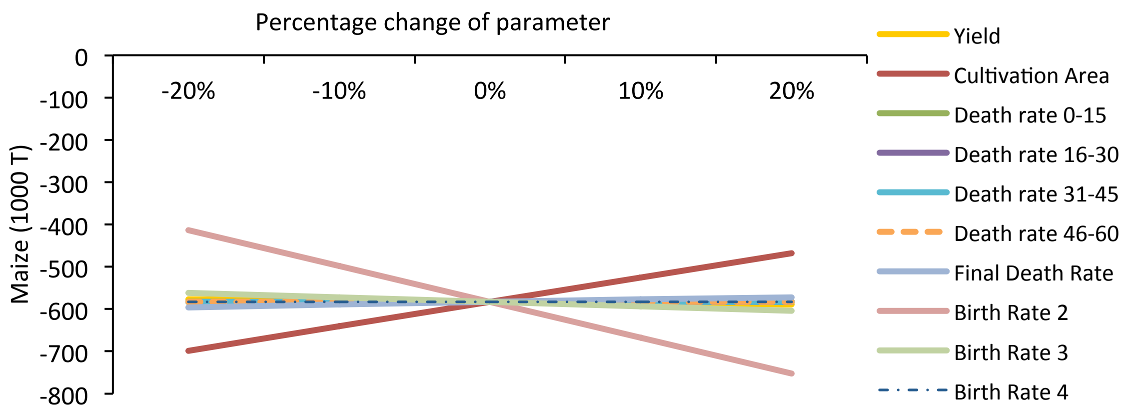

Figure 8 Sensitivity graph for maize with a cultivation area trend value of 22,000 ha yr^{-1}. X-axis shows percentage change of the parameter and the y-axis shows the results in maize crop surplus/deficit. The death rate for the 0-15, 16-30,31-45,46-60 age cohorts and birth rate 4 (age group 46-60) have overlaying lines at the same trend. Deathrate for age group 31-45 and 46-60 lines in the graph show the trend for all these groups.

3.1.4 Model Validation

3.1.3.1 Population model validation

The population model was validated with the historical population data from 1990 till 2014. The model was run for this time period with the same parameters and the 1990 initial values. Therefore the model was validated with the historical behaviour of the population data. Ford (2010) states that this form of test is one of the most common and important tests for model validation. Another version of the historical behaviour test uses the data from one site and to validate with results from another site (Ford 2010). Since there is no second site or dataset for the population of Cameroon, the historical data from 1990 till 2014 was used for the model validation. The birth and death parameters were not based on the linear trend calculation of the historical data and therefore the historical data could be used for validation. By validating with the historical behaviour, the test checks if the model estimates the same trend as the observations show and if there are no obvious biases in the model.

Figure 9 shows that the trend line and model results are very close to the 1:1 line, which is the trend if the model and observations would be exactly the same. This is however a subjective judgment and therefore the Wilcoxon signed ranked test was applied. The Wilcoxon signed ranked test is a non-parametric test (i.e. not assuming normal distribution) and tests the difference between pairs of data such as the model and observed population data per year. The hypothesis is that the difference between the modelled and observed data is not significantly different. This was supported by the Wilcoxon signed ranked test which suggests that p= 0.2 and thus bigger than the critical p value of 0.05. The hypothesis could therefore not be rejected and the observed and modelled data do not significantly differ. Additionally the relationship between the modelled and observed data was tested with the regression test. The result was p=0.000, which means the p value is lower than the critical p value of 0.05 and the modelled and observed data are significantly linearly related. The R^2 of 0.99 in Figure 9 also suggests that the modelled and observed population are strongly associated. A R^2 of 1 would be the best result and therefore it can be concluded that the model and observation results do not significantly differ and have a significant association (Hawkins 2009). The population model and parameters therefore were found to be sufficiently accurate.

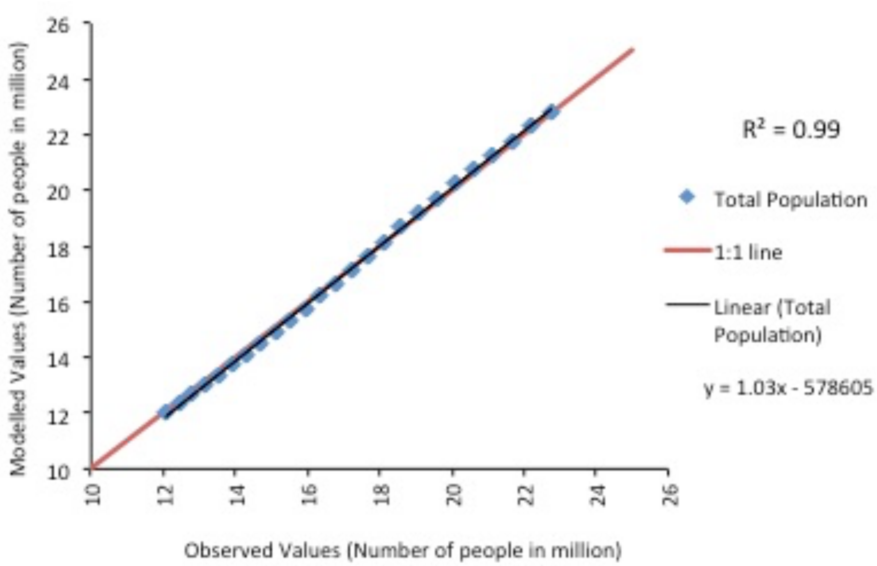

Figure 9 Modelled versus observed values. The red line is the 1:1 line and indicates the trend if the model results would perfectly resemble the observed population. The black line is the trendline of the modelled versus observed data.

3.1.3.2 Crop model validation

The crop model consists of the yield and cultivation area models and parameters. Historical data from 1990 is available for these parameters but the historical trends are affected by economic and technological development. The historical data is therefore unstable and does not fit into a pattern such as a linear fit. Because of the influence of economic and technological factors over time, the historical data could thus not be used for the yield and cultivation area model validation. Additionally, there is no second set of independent data available for the yield or cultivation area in Cameroon. The yield and cultivation area models are therefore not statistically validated and based on reasoning of the determined parameters.

3.2 Qualitative methods

In addition to the quantitative system dynamics model, interviews give the opportunity to examine the opinions, perspectives, experiences and incentives of people regarding grain production, yield, cultivation area trends and food security for Cameroon (Gill et al. 2008). This can be used to see if the model estimates the system dynamics sufficiently. Additionally, interviews can yield more in depth knowledge about a subject, which might not be covered by the quantitative methods (Gill et al. 2008). Especially with concepts such as food security, cultural context and detailed local understanding might prove to be important for the application of the quantitative system dynamics model.

The interviews conducted were open, which means there was little organization and room was left to discuss different questions with the interviewees depending on their responses (Gill et al. 2008). The interviewees were two farmers and an agricultural officer in Cameroon. The interviewees were considered to be key informants. Key informants are experts in their field of knowledge, which means they are able to give a good insight on the topic (Marshall 1996). Trembley (1989) additionally suggested in “Field Research: A sourcebook and Field Manual” that key informants have a role in the community and knowledge regarding the field of study, want and are able to communicate this knowledge. All of the respondents have been practicing agriculture for at least the last fifteen years in Cameroon. In total three interviews were conducted over the phone in English and recorded. Both farmers are also teachers and the agricultural officer is employed with the Ministry of Agriculture and also a practicing farmer. The topics addressed were the current food availability, main challenges for food production, factors that determine food crop yields, factors that contribute to postharvest losses, land availability and use, effects of factors such as climate change, population growth, used seeds, differences between crops and soil fertility. Table 8 shows the respondents’ area of land owned, cultivated crop and intensity of farming. The interview results were used and compared with model results and literature in order to analyze differences or similarities.

Table 8 Overview of the interviewees, the types of crop they cultivated, the total land area owned and the intensity of farming they practiced.

Respondents	Types of crop	Total Land owned	Intensity of farming practice
Food Crop Farmer 1	Maize, rice and pumpkin	1 ha	Subsistence
Food Crop Farmer 2	Maize, beans and rice	2 ha	Subsistence
Agricultural Officer and practicing farmer	Maize, beans, plantains and rice	2 ha	Subsistence

Chapter 4 Results

4.1 Model Results

Table 9 shows that by 2030 the model predicts a surplus for millet and sorghum and a deficit for rice and maize. A deficit means that the production is smaller than the consumption and postharvest loss. The surplus indicates that the production is sufficient to meet the consumption and account for postharvest loss. In all cases there is a difference between the 2015 and 2030 crop surplus/deficit. The following graphs show the model estimation for the separate factors (i.e. production, consumption, postharvest loss, crop available) forming the crop surplus/deficit for each crop.

Table 9 Crop surplus/deficit per year estimated by the model from 2015 till 2030. Crop surplus/deficit is the production minus the consumption and postharvest loss. Rice 1 is modelled rice with cultivation area trend 5,100 ha yr^{-1}, rice 2 is modelled rice with cultivation area trend 9,000 ha yr^{-1}. Maize 1 is modelled maize with cultivation area trend 22,000 ha yr^{-1} and maize 2 is modelled maize with cultivation area trend 42,000 ha yr^{-1}.

Year	Millet (1000 t)	Sorghum (1000 t)	Rice 1 (1000 t)	Rice 2 (1000 t)	Maize 1 (1000 t)	Maize 2 (1000 t)
2015	-9.77	-153.45	-474.75	-474.75	-456.13	-456.13
2016	-8.63	-129.64	-488.77	-483.9	-453.14	-421.65
2017	-7.47	-106.25	-503.42	-493.85	-449.02	-385.34
2018	-6.29	-83.28	-518.68	-504.6	-443.6	-346.87
2019	-5.24	-57.46	-535.03	-516.6	-447.09	-317.2
2020	-4.23	-33.24	-552	-529.37	-452.09	-288.58
2021	-3.25	-10.81	-569.6	-542.87	-458.62	-261.04
2022	-2.19	8.73	-587.77	-557.03	-468.08	-236.17
2023	-1.19	28.31	-606.7	-572.04	-477.72	-210.87
2024	-0.27	47.97	-626.39	-587.88	-487.48	-184.97
2025	0.61	65.73	-646.48	-604.14	-501.71	-163.61
2026	1.47	82.5	-667.47	-621.38	-513.81	-138.93
2027	2.29	98.23	-689.36	-639.62	-523.55	-110.49
2028	2.98	114.02	-711.94	-658.58	-540.94	-90.53
2029	3.7	128.76	-735.21	-678.25	-560.73	-72.74
2030	4.46	142.41	-759.18	-698.64	-582.99	-57.21

The production for both millet and sorghum increases up to 2030. Consumption also continues to increase for both grains and this is driven by the total population growth since the consumption per person is fixed. As can be observed in Figure 10 and 11 the production increases steeper than the consumption. The results in Figure 10 and 11 show that both millet and sorghum have crop deficit for the first half of the time period. The millet has a surplus from 2025 onwards and the overall surplus remains small (Table 9). Sorghum has a surplus from 2022 onwards and this surplus enhances over time (Table 9). Figure 10 and 11 also illustrate that the postharvest loss is the difference between having a surplus or deficit. The consumption alone is lower than the production whereas the consumption and postharvest loss together are more than the production for the first half of the time period. Without the postharvest loss there would have been a surplus earlier.

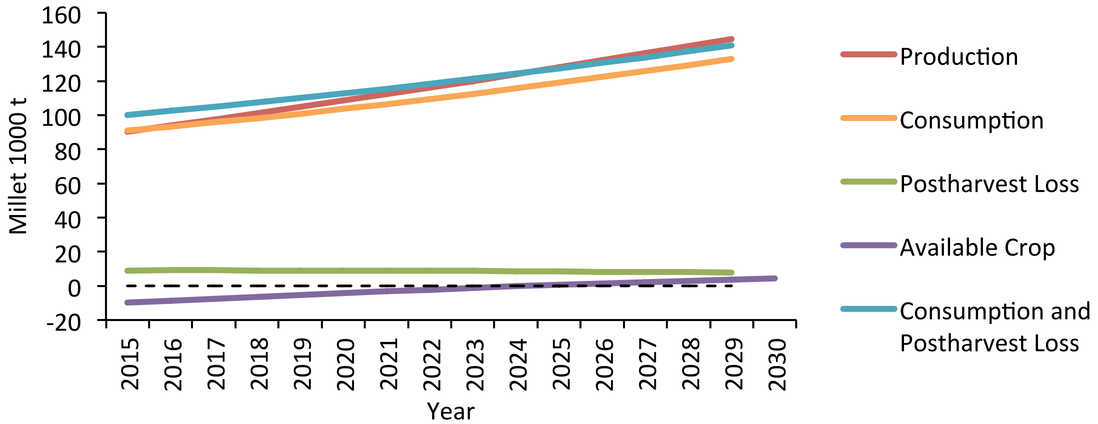

Figure 10 Modeled millet production, consumption, postharvest loss and available crop from 2015 till 2030 for Cameroon. Available crop is the crop surplus/deficit and is calculated by subtracting the consumption and postharvest loss from the production. Dashed black line shows the zero value..

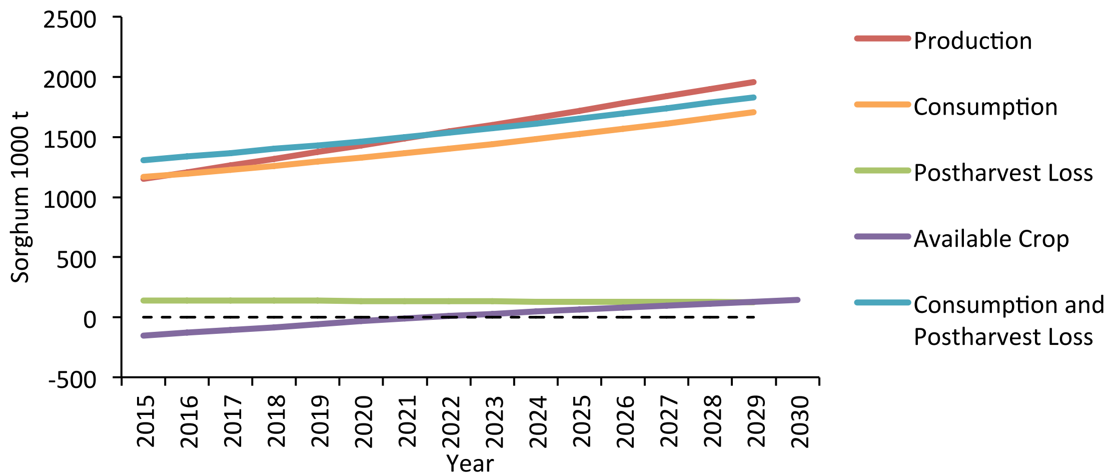

Figure 11 Modeled sorghum production, consumption, postharvest loss and available crop from 2015 till 2030 for Cameroon. The available crop is the crop surplus/deficit and is calculated by subtracting the consumption and postharvest loss from the production. Dashed black line shows the zero value.

The rice production is only slightly increasing for both cultivation area trend values. For rice with cultivation area trend 9,000 ha yr^{-1} the rice production increases more than the 5,100 ha yr^{-1} cultivation area trend. This also causes the smaller deficit for rice with cultivation area trend 9,000 ha yr^{-1}. Overall the production increase is very low because of the negative yield trend, which counteracts the cultivation area trends. Figure 12 and 13 also imply that the slope of rice consumption is steeper than the slope of the rice production, this slope difference was however not significant ($p=0.44$). The slope difference leads to the increasing deficit for both cultivation area trends over time (Table 9). Overall, rice has the highest deficit regardless of the cultivation area trend applied. The postharvest loss for rice is low and does not make a difference in the crop surplus/deficit, as shown in Figure 12 and 13.

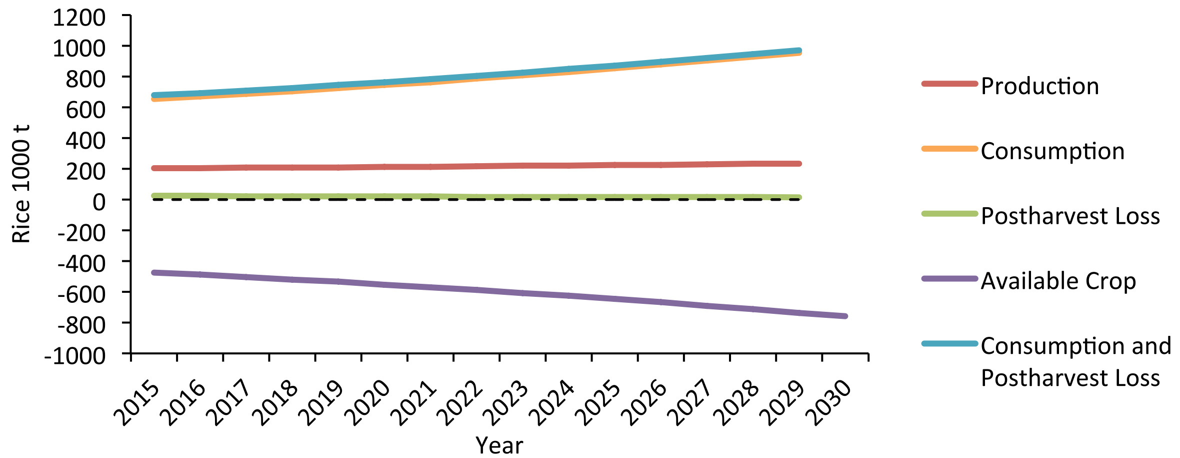

Figure 12 Modeled rice production, consumption, postharvest loss and available crop with the cultivation area trend of 5,100 ha $^{-1}$ from 2015 till 2030. The available crop is the crop surplus/deficit and is calculated by subtracting the consumption and postharvest loss from the production. Dashed black line shows the zero value.

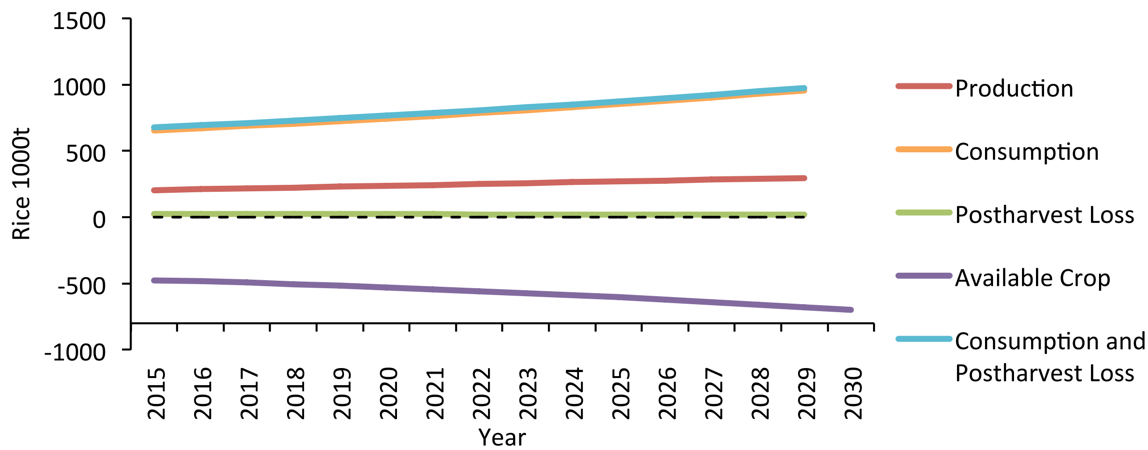

Figure 13 Modeled rice production, consumption, postharvest loss and available crop with the cultivation area trend of 9,000 ha yr $^{-1}$ from 2015 till 2030. The available crops is the crop surplus/deficit and is calculated by subtracting the consumption and postharvest loss from the production. Dashed black line shows the zero value.

Maize production is increasing for both cultivation area trends despite the negative yield trend (Figure 14 and 15). The production with the higher cultivation area trend leads to a higher increase in the production. Consumption is also increasing for both. This increase is steeper than the production increase for the maize with cultivation area trend 22,000 ha yr^{-1} but not for the maize with cultivation area trend 42,000 ha yr^{-1}. For the latter the production increase is steeper than the consumption from 2018 onwards. Maize has a crop deficit for both cultivation area trend values (Table 9). However the cultivation area trend 22,000 ha yr^{-1} leads to an increasingly bigger deficit closer to 2030, whereas the maize with the trend 42,000 ha yr^{-1} becomes less negative closer to 2030. Additionally, Figure 15 suggests that without postharvest loss the deficit of maize with cultivation area trend 42,000 ha yr^{-1} turns into a surplus in 2017/2018. Therefore the postharvest losses and its rates, which is currently almost a quarter of the production, play an important role for the maize availability.

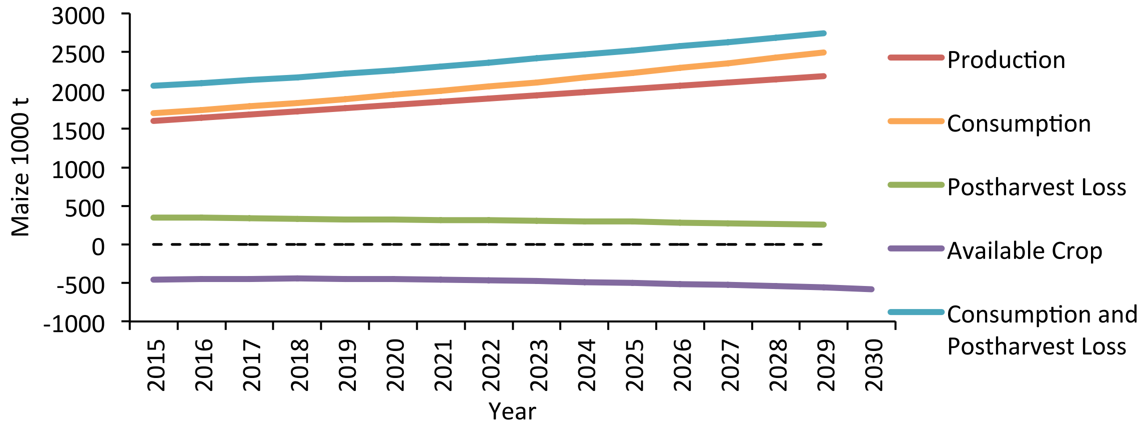

Figure 14 Modeled maize production, consumption, postharvest loss and available crop with the cultivation area trend of 22,000 ha yr^{-1} from 2015 till 2030. The available crop is the crop surplus/deficit and is calculated by subtracting the consumption and postharvest loss from the production. Dashed black line shows the zero value.

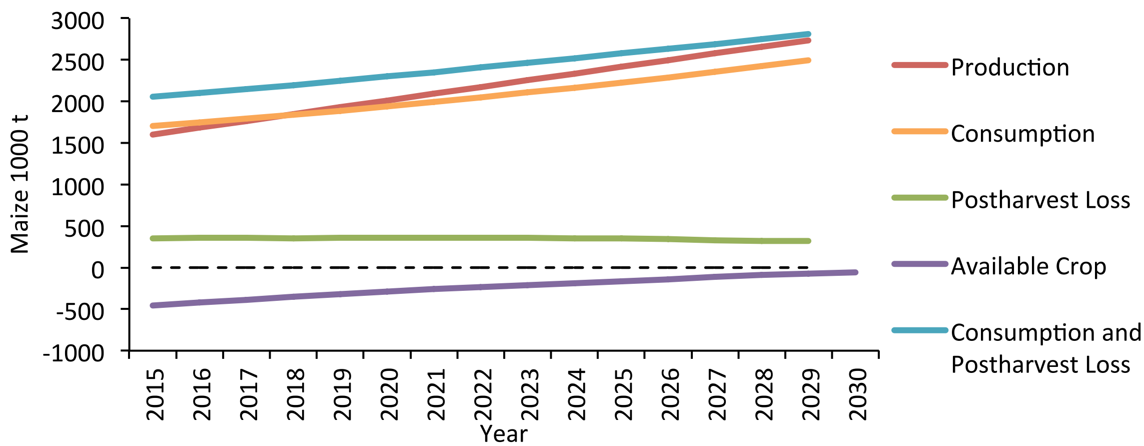

Figure 15 Modeled maize production, consumption, postharvest loss and available crop with the cultivation area trend of 42,000 ha yr^{-1} from 2015 till 2030. The available crop is the crop surplus/deficit and is calculated by subtracting the consumption and postharvest loss from the production. Dashed black line shows the zero value.

4.2 Yield Changes

Table 10 shows the yield trends needed to meet demand in 2016 or 2030 for each grain without changing any other trend values (e.g. cultivation area). Millet and sorghum do not have values for 2030 since these crops already have positive availability in 2030 with the original yield trends. Millet production fulfills the demand in 2025 and sorghum in 2022 when using the original trend values. The original millet trend was 0.5% (Table 5), which means the millet yield trend has to become 8 times its original value to meet demand in the second year the model runs (2016). The sorghum yield growth should increase from 1% per year to 21.5% per year to meet consumption and postharvest loss in 2016.

Maize and rice production was predicted to not meet consumption and postharvest loss in 2030 (Table 5). The rice yield trend was originally -0.08 (-8%) and as Table 10 shows the yield growth has to become positive in order to meet demand in 2030 or 2016. Especially in the case of a cultivation area trend of 5,100 ha yr^{-1}, the yield trend growth has to increase to 14.3% for 2030 and 100% to meet demand in the next model run (2016). The cultivation area trend of 9,000 ha yr^{-1} requires the yield trend growth to be 6% per year to reach demand in 2030 or 96% for the next year. The maize with cultivation area trend 42,000 ha yr^{-1} yield growth has to be 0.024% to meet demand in 2030 or 15.45% to reach this in 2016 or 0.95% and 17.02% for the model with cultivation area trend 22,000 ha yr^{-1} (Table 10). For maize with cultivation area trend 22,000 ha yr^{-1} the yield growth has to be 0.9% to meet demand in 2030 and for maize with cultivation area trend 42,000 ha yr^{-1} this is even smaller, 0.024%.

Table 10 Yield trends needed to meet demand in 2030 or 2016 per grain. Column 2 '2030' shows the yield trend needed to meet consumption and postharvest loss in 2030 and column 3 shows this trend value in 2016 (second model year).

Grain	**Yield Growth Rate– 2030 (%)**	**Yield Growth Rate - 2016 (%)**
Millet	-	4.1
Sorghum	-	21.5
Rice Trend 5,1000 ha yr^{-1}	14.3	100.3
Rice Trend 9,000 ha yr^{-1}	6.37	96.7
Maize Trend 22,000 ha yr^{-1}	0.95	17.02
Maize Trend 42,000 ha yr^{-1}	0.02	15.45

4.3 Interview results

Three interviews were conducted, two with farmers and one with an agricultural officer in the Ngo-Ketunjia region in North West Cameroon. The topics discussed were the overall food production, cultivation area expansion, yield trends, postharvest loss, climate change, soil degradation and future prospects.

Farmer 2 implied that in the Ndop area food production is increasing, although this has not led to a decrease in the prices because the food is also exported to other surrounding areas. It was stressed that this is the case for this particular region. In the North were climate change effects are worse, the production is decreasing. Farmer 1 suggested that prices have even tripled. The production is increasing according to the agricultural officer, who also suggested that the prices are not decreasing as would be expected. The farmers do therefore not get enough in return for their crops, which affects their possibilities for investments and production growth. A reason, for the low prices, according to the agricultural officer, is that the harvest and selling of the crops coincides. There are not enough resources for preservation or storage therefore preserving the harvest is not an option.

The main reason behind the growth in production is expansion of cultivation area according to the interviewees. According to the farmer 1, cultivation land is expanding through cutting down forests and using pasture land. People are encouraged to start up new farms in these areas. The agricultural area can be rented from landlords, who are paid with money or yields, or can be inherited via the male bloodline. The inheritance of land means that the land in most cases has to be divided between the sons, which leads to a decrease in the patches of land owned per person. According to farmer 1, this puts pressure on the farmers to expand their cultivation areas into new areas. Additionally farmer 2 and the agricultural officer suggested that the smaller land patches means mechanization is very difficult because it is difficult for, for example, tractors to reach the small patches of land and work there. The agricultural officer also explained that the government tries to motivate farmers to form cooperatives to solve these problems and that recently a tractor per sub division was made available. Both farmer 1 and agricultural officer also agreed that the growing population is putting pressure on the cultivation area expansion. Firstly, by increasing the need for more food production and thus more cultivation area and, secondly, by using farmland for new settlements, making less available for agriculture.

Regarding yields the opinions are slightly divided. According to farmer 1 the yields are obviously decreasing for groundnuts, maize and cocoyam. He suggested that rice yields might actually have increased and benefitted from the floods in some places, which makes more areas suitable for rice production. Farmer 2 implied that maize yields are decreasing because of exhausted land and that rice yields are increasing. The agricultural officer suggested that yields are increasing especially maize and rice. According to the agricultural officer the production is increasing because farmers use chemical farming, including fertilizers, instead of the organic methods. Fertilizer is mentioned by all three interviewees as strongly related to the yield changes. However, the price of fertilizers is becoming very high, especially for ordinary farmers, and farmer 1 said that the lack of access to fertilizer is the reason behind the decrease in yield for cocoyam, maize and groundnuts. He suggested that the fertilizer prices tripled over the last five years, that this problem is becoming bigger and that this leads to more uncertainty about the yields. Farmer 2 also referred to the problem of the high prizes for fertilizers and states that fertilizer was around 10,000-15,000 francs for 50kg but now it is 20,000 francs. The agriculture officer mentioned that fertilizer is now about 18,000 to 20,000 francs for a bag of 50kg and that these prices reduce the return of farmers for their products even further. These prices make farmers even more unwilling to invest, because they are afraid that they will not earn enough and therefore they invest less, which negatively affects the yields.

One of the main problems identified by all three interviewees is postharvest loss. Especially due to the lower prices, there are no resources available for farmers to improve the storage or preservation capacities. Farmer 1 implies that main causes of postharvest losses are the transport from the farms to the vehicles, which transport the crops to the markets and houses. Crops have to be carried to places where vehicles can actually come and pick up the crops. Additionally farmer 1 and 2 mentioned insects, pests and storage as the main reasons for postharvest losses.

Farmer 2 suggested that processing more of the crops could help solving this problem, such as processing tomatoes into tin tomatoes. The agricultural officer pointed out that postharvest losses are especially large for maize and beans, and that farmers do not have the technology to store the products. Moreover he suggested that processing could help but that there are not enough processing facilities. These postharvest losses discourage farmer to increase the production and therefore play an important role in the food production trends.

Another main change and potential problem for the food production identified by all three interviewees is climate change. All agree that climate change is happening and affecting the food production. They suggest that the rains are becoming more irregular and temperatures are getting higher. Rains are heavy and intense or do not occur at all. Farmer 1 and the agricultural officer mentioned that normally farmers knew that rains would come mid-March and therefore could plan their sowing. However now the rains only occur in mid-April, which is a month later. It is therefore difficult to plan the agricultural activities. Additionally farmer 1 suggested that for 4 years he has not observed the Christmas rain anymore, which normally occurred at the beginning of the dry season till the peak of the dry season. Mentioned consequences of these irregular and shifted rain patterns are pest outbreaks, stream flows, floods and, according to the agricultural officer, the yields are 40% less than 10 years ago due to increased droughts. The fluctuation of the water levels has led to the occurrence of heavy floods or the absence of floods that normally occurred. The late start of the rain season makes it also difficult for farmers who plant crops after each other, according to the agricultural officer. All agricultural activities are done later and then floods wash everything away or pests will attack the crops, as suggested by farmer 1. According to the farmers, most farmers are dependent on natural resources for crop cultivation, which make the consequences of climate changes worse. Additionally the farm inputs are becoming very expensive which makes the farmers even more dependent on natural resources. All agree that if nothing is done about climate change, the food production will decrease.

Soil degradation is also referred to as a problem for further increasing the food production. All interviewees agreed that soil fertility is decreasing. Farmer 1 suggested that ‘people begin to complain that if you do not apply artificial fertilizer than you will not have yields enough’. Moreover he suggested that soil erosion in some areas, especially the hilly areas, is a big problem because the top soils are swept away by floods to the lower laying areas. Farmer 2 agreed that the decrease in soil fertility increases the need for fertilizer, which is difficult with the high prices for fertilizer. The agricultural officer additionally suggested that the intensive use of the land over and over again by farmers depletes the soil from nutrients and negatively affects the yield. He pointed out that the soils in the hilly and higher areas have a lower retention capacity than the lower and flatter areas. One thing done by the officers is setting up farmer dialogues between the livestock and crop farmers in the hope that this might lead to cooperation where the manure of the livestock is used for fertilizing the soils where crop is grown.

Crops are mostly mixed such as rice, maize and beans. This has been a tradition and only the large scale rice and some maize farmers have monocultures. All suggested that the ministry or divisions offer special selected (hybrid) seeds for maize and that the use of these seeds becomes more common. In some cases politicians even hand out these selected seeds for free to gain supporters, according to the farmers. According to farmer 1, the other seeds are acquired via the ordinary way of using the previous yields for seed selection. Farmer 2 suggested the UNVDA (The Upper Noun Valley Development Authority) has selected seeds for rice, which are available for subsided prices. He also implied that the selected seeds help farmers to increase the yields per hectare but that the selected seeds seem more fragile than the traditional maize seeds. The agricultural officer also suggested that farmers realize the selected seeds are not always better than their own seeds. This led to a lack of confidence in the seed producing sector, especially by the ordinary farmers.

The future prospects for the upcoming 15 years according to farmer 1 are that if the farmers continue to have limited access to resource such as irrigation, fertilizers or mechanization the situation will worsen. Additionally, the population growth will take parts of the farmland away and the decrease in available fertile land will lead to further production decreases. Some of the fertile land that is available is hard to reach and so far “there are no prospects of linking the fertile area with farm areas”. The transportation currently used is leading to more crop losses and this will continue if transportation is not improved. Farmer 2 suggested that the youth is not very interested in agriculture and that this will be a problem for the future. If the state would invest in making agriculture more interesting for the youth, the production might increase. Additionally most people do not believe farming is an “occupation somebody can rely on” and people “do not believe that you can survive only from farming”. Lastly, he suggested that the state could make more land available which is currently not used in order to help to increase the production. The agricultural officer expects that the food production will steadily increase up to 2025 or 2030 and could even double if farmers would have better access to resources to add to the food value. But currently the crop prices and thus the farmers’ income are too low for this to happen. Therefore in his opinion there is a problem at the market level and policy is not really addressing food production or markets.

Chapter 5 Discussion

5.1 Crop surplus/deficit

Millet and sorghum start with a deficit but turn into a surplus in 2025 and 2022, respectively (Figure 10 and 11). Figure 10 and 11 show that one of the main reasons is that the production grows faster than the consumption or consumption and postharvest losses. Sorghum and millet are the only two grains with positive yield trends, which contribute to the faster growth of the production. Additionally sorghum also has the second highest cultivation area growth, which contributes to the steep production increase. This could explain why sorghum has the most positive results and reaches a surplus already in 2022. On the consumption per person side, sorghum consumption per person is the highest and millet consumption per person the lowest. These values are however fixed and the consumption growth is driven by the population growth. The growth of the consumption is therefore probably not as high as the production growth.

The rice and maize with cultivation area trend 22,000 ha yr $^{-1}$ have a lower production trend compared to the consumption and postharvest losses trend (Figure 12, 13 and 14). This leads to the increasing deficits instead of the decreasing deficits for sorghum and millet. This difference is caused by the negative yield trends for rice and maize (Table 5). These counteract the positive cultivation area increase and subsequently the production increase. A positive yield trend might already lead to a surplus. A higher cultivation area trend might also lead to a surplus as is shown in the case of maize production. The maize production with a cultivation area trend 42,000 ha yr^{-1} has a deficit up till 2030 but the production trend is higher than the consumption and postharvest loss trend (Figure 15). The deficit is becoming smaller every year as opposed to the deficit becoming larger in the case of maize with cultivation area trend 22,000 ha yr^{-1} (Table 9). Therefore different cultivation area trends lead to different production versus consumption trends and the negative yield trend could be one of the main causes of the deficits.

Rice and maize surplus/deficits were both estimated with two different cultivation area trends, which were based on different time periods (1990-2015 and 2000-2015). It is difficult to judge if the higher trend values based on the 2000-2015 period are just outliers or that these trend will continue for another 15 years. The maize cultivation area data (Figure 3) show that the peak in 2013 might have influenced the trend value based on the 2000-2015 time period. Figure 3 shows the cultivation area data for rice, and also illustrates that there is a peak in 2014, which will have positively biased the 2000-2015 trend value as opposed to the 1995-2015 data. A more conservative guess would be to use the lower cultivation area trend values. The effect of the different cultivation area trend values particularly affected the maize results. The 42,000 ha yr $^{-1}$ maize yield trend value leads to a steeper trend of the production compared to the consumption and the deficit is therefore decreasing, as previously discussed (Figure 14 and 15). The different rice cultivation area values have different results in the deficit numbers, but in both cases there is a growing deficit (Table 5). Since the model is very sensitive to the cultivation area parameter, the use of different baseline for the cultivation area trend leads to different crop surplus/deficit results.

The interview results also suggest that the production is increasing for all crops, which is similar to the model results. The production is increasing but for crops such as maize and rice the consumption is larger than the production leading to deficits in the model. The interviews clarified that cultivation area expansion, by turning forests or pastureland into cultivation area, is the main reason behind this current production growth. The recent high cultivation area trends for rice and maize show this increase. The population increase will however enhance the pressure on the need of land for settlement and therefore slow down the cultivation area increase. Moreover, soil degradation, because of intensive use of the available land, will make cultivation area expansion more challenging, as suggested by the interviewees. One of the interviewee's suggested that farmers complain that without fertilizers that not enough yields can be acquired from the cultivated land. Therefore cultivation area has been growing extensively but will reach eventual limits by population growth and soil degradation.

The interviewees estimate that if farmers remain mainly dependent on natural resources the situation might worsen, which means deficits might become larger because further production increase will be more difficult. Additional factors are the population growth and the lack of interest for agriculture by the youth. For rice and maize, the model indeed estimates that the deficits will become larger. The use of land for settlements and soil degradation is not explicitly included in the model but using the more conservative numbers for the cultivation area expansion might reflect these pressures. Lastly, one of the interviewees suggested that the food production might double if farmers would have more access to resources and otherwise steadily increase. Currently the prices are too low for farmers to have sufficient income to buy fertilizers or mechanization and doubling of the food production is unlikely to happen. The model results show indeed that food production is estimated to steadily increase but will not double in the upcoming 15 years. Therefore this corresponds with the projections of the interviewees. The access to resources and the dependence on the natural resources is one of the main factors that will affect the crop production.

5.2 Postharvest loss

The postharvest losses, which contribute to the consumption and postharvest loss trend, are less for millet and sorghum than for maize (Table 7). Maize has the highest postharvest loss percentage of 22% per year, which contributes to maize having the second highest deficit. Especially for the maize with cultivation area trend 42,000 ha yr^{-1} the postharvest loss plays an important role. Without postharvest loss the maize cultivation area trend 42,000 ha yr^{-1} would have had a surplus in 2018 (Table 12 Appendix 8.1). For maize cultivation area trend 22,000 ha yr^{-1}, there would still be an increasing deficit up to 2030 but this deficit would be smaller. The interview results also suggest that postharvest losses are highest for maize. By contrast, rice has a lower postharvest loss of 11.2% and the rice postharvest loss is not the main reason for the rice deficit (Table 7). Even without the postharvest loss the rice consumption would be higher than the production and there would be a deficit for both cultivation area trend versions (Table 12 Appendix 8.1). Figures 10 and 11 show that if postharvest loss was not included, there might have been a sorghum and millet surplus in 2016. This is supported by Table 12 in appendix 8.1, where the model results without postharvest loss are shown. The postharvest losses are not included in the sensitivity analysis because it is not a fixed value but one that changes over time (half by 2030). However the results without postharvest losses suggest that the model yields very different results when excluding postharvest loss. Postharvest losses are therefore very important for the crop availability and can change a deficit into a surplus. The interviewees also pointed out that postharvest loss is a big problem for farmers in Cameroon.

The postharvest loss decline to half the rate by 2030 might be too positive, since this decline is based on a suggested goal. When considering the postharvest losses of previous years in APHLIS there has been no change in postharvest losses for the previous 5 years (2008-2013) (African Postharvest Losses Information System 2016). Therefore the postharvest loss decline in this project is likely to be more positive than the real postharvest loss trend for the upcoming 15 years will be. There are several factors, which could decrease postharvest losses. Postharvest losses might decrease if the agricultural, storage or waste technology increase and its prices decrease in the upcoming 15 years (Kaminski and Christiaensen 2014). A substantial increase in the economy of Cameroon could lead to more available resources for farmers, which subsequently could decrease the postharvest losses. There are also factors that could increase postharvest losses. Main factors are insects and rodents/pests present (biotic factor) (Kaminski and Christiaensen 2014). Insects and pest thrive under warm conditions and a warmer and more humid climate will enhance their presence and increase storage losses (Kaminski and Christiaensen 2014). The interview results suggest that main reasons for postharvest loss are transportation, pests, storage and preservation. Furthermore the interviews confirm that the lack of resources by the farmers is the main reason that the storage and preservation resources cannot be improved. It was suggested processing the crops might be a solution but so far there are not enough processing facilities. It is difficult therefore to conclude how postharvest losses will develop in the upcoming 16 years. There are however suggestions regarding what the aim should be which is to reduce the postharvest loss rate by half in 2030. Based on the interview results, the future of postharvest losses seem to depend on the resources that will be available for the farmers to access, but with the current low prices for crops and high prices for fertilizers and other technologies, improvement is difficult.

5.3 Parameters

Trends in crop yield and cultivation area were determined using historical data (Table 5 and 6). The time period chosen for the trend calculation can generate different trend values. Especially for maize and rice yield trends, which yield data did not have a very linear fit, the use of different time periods led to different trend values ranging from negative to positive trends. The 1990-2015 cultivation area trends were lower than the 2000-2015 for both rice and maize. The definition of high or low (outlier) values might have been different when using larger datasets (e.g. 1950-2015). It could be that the 2000-2015 period contained outliers, which might not have been clear from the 1990-2015 data. Outliers might have skewed the estimations. It is however assumed that outliers will also occur in the future and that these will be reflected by past outliers.

Whereas for cultivation area the interviewees' suggestions are that this is increasing, which matches the data, this is not always the case for the yield trends. According to the farmers there is a decrease for most crop yields such as maize but rice yields are increasing. The agricultural officer suggested that the yields for all crops are increasing, except beans. The yield data suggests that the yields for sorghum and millet are increasing but not for rice and maize. Especially for rice the data seems to show negative yield trend compared to the positive yield trend according to the interview results. The difference could be caused by the interviewees' opinions being based on a certain area, whereas the data is on national level. The time considered for the yield trend might have led to the difference because when looking at the yield data for the last 3-4 years rice and maize yields are increasing. The reference time for the trend therefore makes a difference.

Another argument to use the data from the last 16 years is that the time period estimated from 2015 to 2030 is also 16 years. Therefore the trends are based on a period of time equal to which they are used to estimate the trends. It is better to use the most recent data because this is more likely to realistically reflect the upcoming years. It could be however that economic or climate situations might change. This will affect the future 16 years trend. The economic situation in Cameroon might for example worsen, which could drastically affect the food prices, agricultural subsidies or resources available and therefore the trend in cultivation area, yield or consumption. An example, as discussed in the interviews, is the current low prices for the crops but high prices for the fertilizers, which affects the possibilities for food production growth. This is however part of the uncertainty of the model and difficult to predict.

R^2 was used to assess how well the average linear trend used reflected the real data for cultivation area, yield, and population. The R^2 value for maize yield was particularly low which would indicate that the association between the model and observed value is low. A low R^2 does not automatically mean the model is bad. It means that only a low percentage of the variability in one variable (model) is associated with the variability in another variable, in this case the observation (Hawkins 2009). Since the model uses mainly linear trends, this can lead to a low association with the actual data. Furthermore the R^2 does not give an indication of the bias of the trend and this should be taken into account (Hawkins 2009).

5.4 Integrated Model

The sensitivity analysis showed that the model is most sensitive to cultivation area, and birth rate 2. In the sensitivity analysis of the maize model with the 22,000 ha yr^{-1} cultivation area trend, the model is slightly more sensitive to birthrate 2 than to the cultivation area (Figure 8). For the model with the 42,000 ha yr^{-1} cultivation area trend, the model is more sensitive to the cultivation area parameter than to birthrate 2. This could be caused by the doubling of the value for the cultivation area, 10% of 42,000 ha yr^{-1} is in absolute numbers double the amount of 10% of 22,000 ha yr^{-1}. Additionally the cultivation area is only multiplied with the yield before it is included in the crop surplus/deficit calculation. It is therefore not affected by other parameters unlike the population model parameters. Regarding birthrate 2, the sensitivity might be caused by the relative high value compared to the other birthrates. Additionally birthrate 2 is assigned to the 16-30 age group, which is the second biggest age group. The other models for sorghum, millet, rice with cultivation area trend 5,100 ha yr^{-1} and rice with cultivation area trend 9,000 ha yr^{-1} are also most sensitive to the cultivation area and birthrate 2 (appendix 8.2). Sorghum and maize have the highest cultivation area trend, which could explain the higher sensitivity to the cultivation area instead of birthrate 2. The sensitivity implies that these model parameters should especially be carefully chosen.

After the cultivation area parameter and birthrate 2, the model is most sensitive to birth rate 3 (age group 3, 31-45 years), final death rate (age group 5, 61+ years) and yield (Figure 7 and 8). Birth rate 3 is the second highest birth rate and it is lower than the final death rate. The higher sensitivity of birthrate 3 can be explained by the size of the age group. Age group 31-45 is bigger in size than the 61 + age group, to which the final death rate is applied (Table 4). The sensitivity of the final death rate could be clarified by the high value of the assigned rate. Yield has a very low trend in (-0.002) in the maize model and this could explain the lower sensitivity. In the other models the yield trend is steeper and these models are more sensitive to the yield (appendix 8.2). The other parameters have low values and are affected by several other parameters in the population model before affecting the final surplus/deficit model.

The integrated model is divided in several submodels of which the cultivation area submodel and yield submodel form the production. These submodels estimate trends of the different factors from 2015 to 2030. In most cases this is a linear trend such as the cultivation area submodel. In reality the cultivation area is not only limited by the area of Cameroon itself, but also by the amount of area which would be suitable for the crop cultivation or what is not used for urbanization, infrastructure or water bodies. The land, which is currently cultivated, could be more suitable for agriculture than the remaining land because farmers will more likely use suitable land first. The limit for cultivation area per crop might therefore be reached quicker than the model estimates. Additionally the new cultivation area land might not be as suitable and have lower yields. As the interview results point out the growth of the population will eventually put pressure on the cultivation area through increased demand for settlement areas. On the other hand the interviewees stated that the inheritance of the land leads to each person having smaller pieces of land, which will increase the pressure on increase the cultivation area again. To include these other factors, submodels could be added to estimate urbanization and the area suitable to grow the selected crops.

The other model in the production model is the yield submodel. This submodel is not linear because it is limited by an asymptote, which is the maximum potential yield or lowest occurring yield. The yield will in reality not increase or decrease as smoothly as the model estimates. According to the interviewees, the yield is very dependent on the access to fertilizers. The current low returns for the crops and the high fertilizer prices make fertilizers inaccessible for farmers and a change in this access might suddenly increase the yield. Additionally the interviewees suggest that for maize, hybrid seeds are more commonly used, which increase the yield but are also more fragile. It is almost impossible to predict the accessibility to resources, such as fertilizers and hybrid seeds, in the upcoming 16 years since these are dependent on the economy and technological development. The simplified average estimation used in this project does reduce the introduction of errors and uncertainties and estimates an average trend.

The population submodel divides the population in age groups of 15 years wide. This makes it possible to be more accurate concerning the death and birthrates. For this purpose the 15 year wide groups divide the population in such a way there are clear divisions between the separate birth and death rates. On the other hand age groups of 15 years are still quite large and are still not able to indicate how many people there are per age year because within the age group the model assigns an equal number of people to each age. Since the main interest is to get the total population, this group width will be sufficient for this project.

The model estimates the crop surplus/deficits on a national scale with annual data. There are therefore no specific estimations for each region in Cameroon and it assumes the produced crops are available all over Cameroon. This might be unrealistic because of the diverse climate and vegetation regimes in Cameroon, which makes different areas suitable for different crops. As was suggested in the interviews, the region in the North has less of a production increase compared to the area of the interviewees. Additionally one of the interviewees explained that crops are exported to other regions from the agricultural towns like Ndop. The soil degradation and nutrient levels are also different in each region. Higher located areas experience more nutrients leaching to the low laying areas, according to the interviewees. It is therefore possible that there might be a surplus in some regions of Cameroon while there is a deficit in other regions.

Another factor excluded in this model is the export and import of the crops. A deficit in the crop production will lead to a higher demand to import this crop from other countries, whereas a surplus could mean this crop can be exported. According to the FAOSTAT data Cameroon received a cereal aid shipment of 11,135 t in 2015 and had a cereal import ratio of 25.8% over 2009-2011 (FAOSTAT 2016). The 2015 deficit results of this model for all four crops are therefore supported by this data. For the crops modeled here, the import and export data for 2013 is shown in Table 11. The data from year 2013 is shown because this is the most recent data in the FAOSTAT database.

Table 11 Import and export in tonnes for maize, rice, millet and sorghum according to the USDA and FAOSTAT databases. Stripe indicates that there is no data available and zero indicates when the data available suggests the quantity is 0.

Grains	FAOSTAT Import (t)	FAOSTAT Export (t)	USDA Import (t)	USDA Export (t)
Maize	13,309	1	10,000	0
Rice	753,263	982	525,000	-
Millet	1,002	0	-	-
Sorghum	32,870	0	10,000	-

The export and import data implies that all four grains had to be imported, which corresponds to deficit estimations for 2015 for all four crops. According to the FAOSTAT data rice was also exported in 2013, which is difficult to explain when the import and deficiencies are so high. The different databases seem to give different numbers regarding the import and export data. This could be due to the use of different sources. The USDA database provides also import and export data for 2015/2016 which is for maize 25,000 tonnes import and no export, for rice 530,000 tonnes import and 25,000 tonnes of sorghum import. Out of these four crops, rice has the highest import numbers. The model results also suggest that rice has the highest deficits and this is supported by the import data, which is the highest for rice and even larger than the current local production. The model results however suggest that maize is the second grain with the highest deficits but this is not reflected in the import data, where sorghum is the second most imported grain. This model focused on the domestic production and consumption of grains in Cameroon and therefore did not include the import and export data. Although many SSA countries import grains, the domestic production is one of the most important factors in the improvement of food security (FAO 2003).

Overall, more submodels could be added to the model in order to increase the reality of the simulation. However, most submodels were not included because more submodels will lead to more complexity and parameters, which are likely to increase the uncertainties and errors in the model.

5.5 Yield Change

In order to meet demand in 2030, both rice and maize will need an increase in yield, whereas sorghum and millet are estimated to already meet demand in 2030. Rice yield would have to increase most (Table 10) probably because it has currently the most negative yield trend and the largest deficits. The increase in yield growth for maize with cultivation area trend 42,000 ha yr^{-1} to meet demand in 2030 is small, which is due to the already decreasing deficit with the original yield value. The necessary yield trend change for maize with cultivation area trend 42,000 ha yr^{-1} could be reachable with technologies becoming cheaper and more easily available. So far however the prices for resources to increase yields are too high for farmers, according to the interviewees. The trend value needed for maize with cultivation area trend 22,000 ha yr^{-1} (0.09 t/ha/yr) is high when considering the range of yield trend values the crops currently have. A combination of increasing yield and cultivation area might however make it easier for rice and maize to meet demand in 2030. The possibility of this growth will depend on several factors such as urbanization and prices, which put pressure on the growth of yield and cultivation area.

5.6 Climate Change

The current model does not include climate change as a factor, which can alternate future grain production. Bele et al. (2010) suggests that climate change will have substantial effects on Cameroon because of three main reasons: 1) Poverty will worsen due to climate change in Cameroon where most current natural disaster are climate related, 2) the population is reliant on resources for necessary activities such as agriculture but the resources for this activity are easily affected by climate change. 90% of the agriculture in Cameroon is for example rainfed and therefore heavily dependent on the rainy season. 3) the poorest societies are already struggling to deal with the current climate and have few facilities or possibilities to cope with future climate change. These groups are most dependent on climate sensitive resources, such as agriculture (Bele et al. 2010). Therefore agriculture belongs to one of the most climate vulnerable parts of Cameroon's community (Bele et al. 2010). This is supported by the interviewees' opinions, which suggest that if nothing is done about climate change food production will decrease because most farmers are dependent on natural resources.

Ngondjeb et al. (2013) conducted interviews with farmers in Cameroon regarding climate change and its effect on Cameroon's agriculture. 56% of the respondents noticed average temperature differences and 72% rainfall variation (Ngondjeb et al. 2013). Most respondents answered that temperature increased (77%) over the last 20 years and precipitation decreased (72% of the respondents) (Ngondjeb et al. 2013). This is supported by Molua and Lambi (2007) who suggest rainfall already diminished per decade more than 2% since 1960. The UNDP (United Nations Development Programme) Cameroon climate change profile data also states that temperature is increasing 0.15 degrees Celsius per decade and that the increase is highest in the North, as was suggested in the interviews of this project (McSweeney et al. 2010). The UNDP report also implies that rainfall has decreased by approximately 2.9mm per month per decade (McSweeney et al. 2010). Additionally the interviewees of this project also agreed that climate change is observable with more irregular rains and higher temperatures. The interviewees of this research project mentioned that normally rain season would start in mid-March but this has become now mid-April, leading to more uncertainties regarding the planning of agricultural activities and yields. One way of dealing with the change in climate factors is to adapt the agricultural practices. However, according to Ngondjeb et al. (2013), 39% the interviewees answered that they did not use adaptations, 29% that they use soil conservations, 13% crop varieties, 11% early and late planting, 5%planting trees and 3% use irrigations. Many of these limitations are related to lack of resources and show the strong relation between poverty and environment. Land tenure pushes farmer to intensively use the small land areas they use and the lack of money makes them unable to buy the needed technology or other resources. The interview results from this project also suggest that main problems for adaptation are the difficulties to access resources such as fertilizers and irrigation. Additionally the inheritance of land by the sons decreases the land per person and increases the pressure on the land that is available. Moreover the interview results of this project suggest that it is more difficult to plan agricultural activities and therefore to plan when and if children can get out of school to help with the farm.

According to Tingem et al. (2008) more frequent extreme temperatures could make it impossible to grow maize or sorghum in large areas of Cameroon. This would lead to a decrease the cultivation area available and increase the grain deficiencies. Molua (2008) found that the agricultural production of Cameroon could grow with climate change under scenario A (+1.5C temperature and +15% precipitation) and B (+2.5C temperature and +8.5% precipitation). This would however be more slowly than without climate change. Furthermore it was found that irrigation and other adaptations are extremely important and the lack of these could lead to 46% crop loss under scenario C (+3.5 temperature and +4.5% precipitation) (Molua 2008). This in combination with the interview data by Ngondjeb et al. (2013), where most respondents did not use adaptations strategies and only 3% used irrigation, suggest that climate change will have negative effects on the agricultural production in Cameroon. Moreover the interviews with farmers in the Ngo-Ketunjia region point out that without increased access to resources such as fertilizers and irrigation, climate change will decrease the yields. The mentioned consequences of climate change are pest outbreaks, change in stream flows, no floods or heavy unexpected floods and so far a decrease in 40% in the yields is observed due to droughts.

Yield forms an important factor in the agricultural production and is sensitive to three forms of climate irregularity: 1) differences in the averages of factors like temperate and precipitation, 2) differences in distribution of climatic events, 3) differences in both point 1 and point 2 (Laux et al. 2010). Rosenzweig and Parry (1994) suggested, after combining various studies that in low latitudes (where Cameroon is located) modelled yield will most likely decrease. The predicted increase in distribution of temperature and rainfall (more extreme events) due to climate change will most likely be the main determinants of crop yield and enhance differentiation of yields (Laux et al. 2010; Tingem et al. 2008). Laux et al. (2010) modelled the effect of climate change on maize crop yields in Cameroon. The results show that the yields would slightly increase for 2020 but substantially decrease in 2080 for the A2 and B2 scenario. The A2 scenario has medium high greenhouse gas emission and the B2 is a more positive scenario with medium low emissions (Laux et al. 2010). They suggest that the CO_2 fertilization will counteract the decreasing yield due to variation in temperature and rain. Without the CO_2 fertilization yields will decline in 2020 (15%) and in 2080 (25%) (Laux et al. 2010). Other sources such as Nakicenovic and Swart in a special report of the IPCC (IPCC 2000) however suggest that before 2050 the CO_2 fertilization will not affect the yield. Tingem et al. (2008) also modelled yields for maize and sorghum in Cameroon under climate change scenario A2 and B2 and concluded that these yields are estimated to decrease by 14.6% and 39.9%, respectively, by 2080. Furthermore, they suggested that all climate scenarios lead to an overall yield decrease for all regions in Cameroon (Tingem et al. 2008). Only the Ngaoundere (Central-North) and Kribi (South) regions were projected to have small maize yield increases due to low increase in temperature (Tingem et al. 2008). The current model suggests sorghum and millet yield trends are positive based on the historical data. These are also the crops for which it is predicted by the model that there will be a surplus in 2030. As suggested by the literature, climate change could negatively affect these crops and alter the yield estimates in a negative direction. Sorghum and millet yield could potentially become negative under certain climate change scenarios and worsen the rice and maize yields.

The decisions that will be made regarding climate change adaptations and mitigation will influence the production and consumption of grains in 2030. This is currently not included in the model because that will make the model more complex and introduce more uncertainties. Especially because the exact climate change scenario for Cameroon is difficult to predict. So far Cameroon has not taken concrete steps to adapt or mitigate climate change (Bele et al. 2010). Without interventions climate change could lead to increased postharvest losses, decreased yield and less suitable cultivation areas due to higher temperature, less rain and the variation of these two factors. Increased postharvest loss and decreased yield and cultivation area would all decrease the production and increase the grain deficits.

5.7 Databases and definitions

For most of the cultivation area and yield data of the four crops the differences between the FAOSTAT and USDA databases are not extremely large. The import and export data for the crops, previously mentioned, are different for the FAOSTAT and USDA databases. These differences could be caused by the use of different sources. The FAO does provide data were the USDA sometimes does not, such as the sorghum data before 2000 and population data. On the other hand the USDA data includes 2015 whereas the FAOSTAT data is only till 2014. The FAO database provides nutritional supply values, which could be valuable for further research into food security utilization. Overall it is important to consider which database is used for the model parameters since different parameters leads to different results. Especially, for the parameters to which the model is sensitive such as the cultivation area, birth rate 2 and yield (Appendix 8.2).

Production is compared with demand in the form of consumption. The consumption does account for availability and accessibility in the food security definition but it does not include the utilization including the nutrition values. The model only addresses grains, which are the main part of the diet in Cameroon, but can never meet the full dietary requirements or lead to food security. To fulfill the utilization part of food security other components of the diet such as vegetables, seed/nuts, fruits and dairy products should also be considered. The consumption does not take into account the various accessibility factors, such as money, infrastructure and resources. Therefore it cannot show the separate access factors and their status. The quality of the crops in Cameroon is also not included because there is barely any regional crop quality data. Additionally the model only works with annual consumption or production and therefore does not look into seasonal differences or meeting consumption ‘at all times’ during the year. This is officially a part of the definition of food security but requires more detailed data. Furthermore the model uses the population as a whole and does not consider different income groups’ distribution or household level data.

In the consumption data food, seeds, consumed crop for processing and feed is included. Since the consumption baseline is set to be 2015, it is assumed that the consumption for seeds, processing and feed will remain the same per person over the time range 2015-2030. This might not be realistic since an increase in the wealth per person often leads to higher meat consumption per person. Subsequently higher meat consumption will increase the need for more feed to produce more meat. An increase in wealth will therefore increase in the feed used per person and thus increase the total consumption per person. The need for seed consumption might also increase if the area available for grain cultivation increases per person and more area can be sown. Another submodel could be added to address the change in consumption per person itself but this will introduce more potential for errors and uncertainties.

Chapter 6 Conclusion

In conclusion, the model estimates that the surplus or deficit of sorghum, millet, maize and rice will differ between 2015 and 2030. For millet and sorghum it is predicted that there will be a surplus by 2030 whereas for rice and maize a deficit is predicted in 2030 for both cultivation area trends. The rice crop and maize with cultivation area 22,000 ha yr^{-1} will have a growing deficit but the maize with cultivation area 42,000 ha yr^{-1} will have a decreasing deficit. One of the reasons behind the deficit can be the negative yield trend for maize and rice. It was expected that there would be deficits in 2030 for all four crops, which is not the case. Therefore the hypothesis of difference between 2015 and 2030 is accepted but not the expectation of a deficit for all four crops. The different results for the cultivation areas also point out that the baseline period chosen for the linear trend calculation is very important. The yield change needed for maize and rice to meet consumption in 2030 is small for maize but seems challenging for rice.

The interview results suggest that the production is likely to increase but that the increase will depend heavily on climate change adaptation and the access to resources such as irrigation, hybrid seeds, mechanization and fertilizers, which make farmers less dependent on natural resources. Up till now most focus has been on expanding the cultivation area as opposed to the yield per hectare. It was agreed that climate change is happening and that temperatures are increasing and rainfall is becoming more irregular. Main challenges for further increase of the crop production are the low revenue for the crops and high prices for resources such as fertilizers and mechanization. Additionally the population growth will put pressure on the cultivation area expansion and soil degradation will make farmers even more dependent on the access to artificial resources. Postharvest loss is also one of the main problems and also for this problem the access to resources for increasing the preservation time, storage capacity or processing facilities will determine if postharvest losses will decrease or increase.

Further research could look into adding submodels addressing factors such as climate change or specific climate and economic scenarios. Lastly, there are many uncertainties in the prediction of food production and further research could look into these uncertainties in order to clarify the likeliness of certain scenarios.

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Appendices

8.1 Results without postharvest loss

Table 12 Crop surplus/deficit per year from 2015 till 2030 excluding the postharvest loss as estimated by the model. Crop surplus/deficit is the production minus the consumption. Rice 1 is modelled rice with cultivation area trend 5,100 ha yr^{-1}, rice 2 is modelled rice with cultivation area trend 9,000 ha yr^{-1}. Maize 1 is modelled maize with cultivation area trend 22,000 ha yr^{-1} and maize 2 is modelled maize with cultivation area trend 42,000 ha yr^{-1}.

Year	Millet (1000 t)	Sorghum (1000 t)	Rice 1 (1000 t)	Rice 2 (1000 t)	Maize 1 (1000 t)	Maize 2 (1000 t)
2015	-0.74	-15.21	-450.64	-450.64	-104.13	-104.13
2016	0.47	9.85	-465.52	-460.02	-105.08	-65.12
2017	1.63	34.07	-481.08	-470.35	-108.08	-28.24
2018	2.75	57.43	-497.31	-481.61	-113.13	6.5
2019	3.82	79.91	-514.21	-493.76	-120.25	39.09
2020	4.83	101.49	-531.79	-506.77	-129.45	69.52
2021	5.79	122.16	-550.04	-520.62	-140.74	97.77
2022	6.7	141.9	-568.97	-535.3	-154.15	123.83
2023	7.55	160.7	-588.57	-550.77	-169.66	147.69
2024	8.34	178.55	-608.85	-567.03	-187.3	169.35
2025	9.08	195.43	-629.81	-584.07	-207.08	188.8
2026	9.77	211.32	-651.47	-601.88	-229	206.02
2027	10.39	226.23	-673.81	-620.45	-253.06	221.01
2028	10.96	240.13	-696.85	-639.77	-279.28	233.77
2029	11.46	253.01	-720.59	-659.84	-307.66	244.29
2030	11.91	264.87	-745.03	-680.66	-338.21	252.55

8.2 Additional Sensitivity results

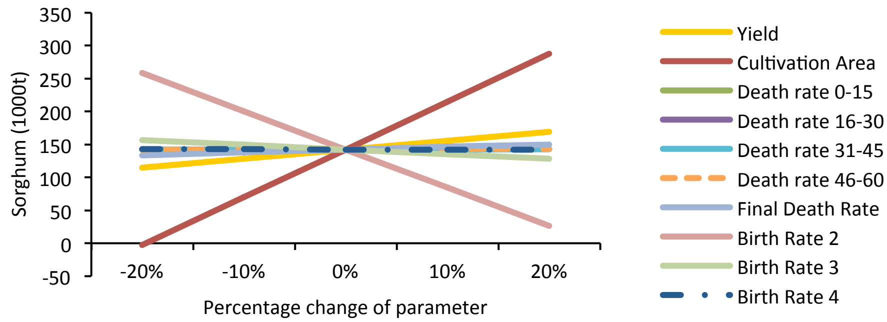

Figure 16 Sensitivity graph for sorghum. X-axis shows percentage change of the parameter. The death rate for the 0-15, 16-30, 31-45,46-60 and birth rate 4 have overlaying lines at the same trend. Birthrate 4 shows trend for all these groups.

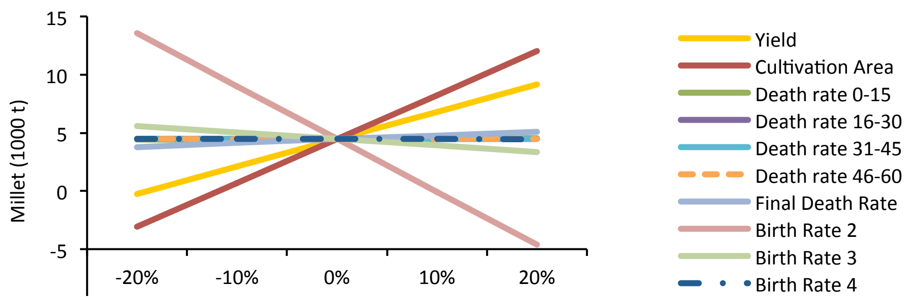

Figure 17 Sensitivity graph for millet. The x-axis shows the percentage change of the parameter. The death rate for the 0-15, 16-30, 31-45,46-60 and birth rate 4 have overlaying lines at the same trend. Birthrate 4 shows trend for all these groups.

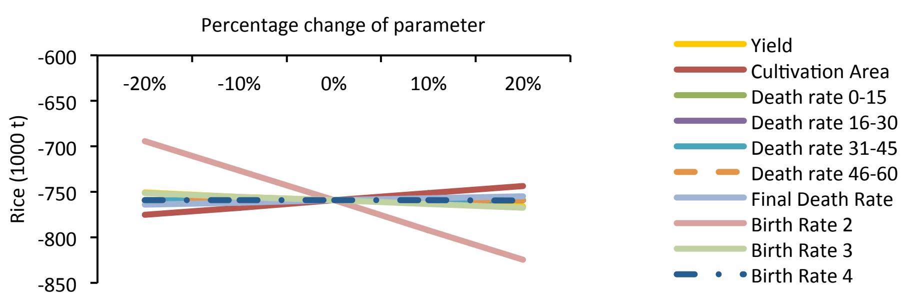

Figure 18 Sensitivity graph for rice with a cultivation area trend of 9,000 ha yr^{-1}. The x-axis shows the percentage change of the parameter. The death rate for the 0-15, 16-30, 31-45, 46-60 and birth rate 4 have overlaying lines at the same trend. Birthrate 4 shows trend for all these groups.

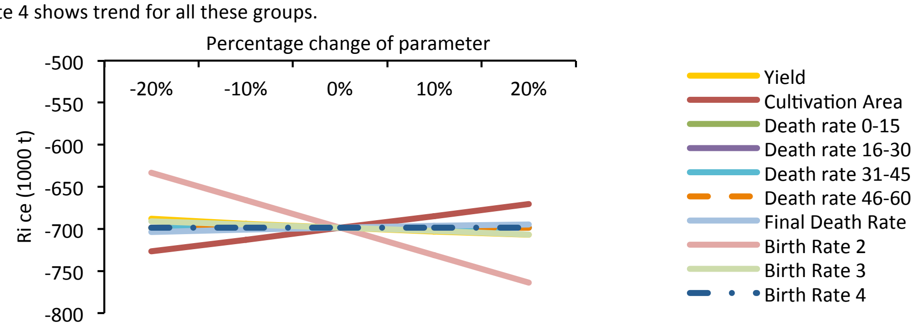

Figure 19 Sensitivity graph for rice with a cultivation area trend of 5,100 ha yr^{-1}. The x-axis shows the percentage change of the parameter. The death rate for the 0-15, 16-30, 31-45, 46-60 and birth rate 4 have overlaying lines at the same trend. Birthrate 4 shows trend for all these groups.

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