Crop Yield Gaps in Cameroon

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Abstract Although food crop yields per hectare have generally been increasing in Cameroon since 1961, the food price crisis of 2008 and the ensuing social unrest and fatalities raised concerns about the country's ability to meet the food needs of its population. This study examines the country's potential for increasing crop yields and food production to meet this food security challenge. Fuzzy set theory is used to develop a biophysical spatial suitability model for different crops, which in turn is employed to ascertain whether crop production is carried out in biophysically suited areas. We use linear regression to examine the trend of yield development over the last half century. On the basis of yield data from experimental stations and farmers' fields we assess the yield gap for major food crops. We find that yields have generally been increasing over the last half century and that agricultural policies can have significant effects on them. To a large extent, food crops are cultivated in areas that are biophysically suited for their cultivation, meaning that the yield gap is not a problem of biophysical suitability. Notwithstanding, there are significantly large yield gaps between actual yields on farmers' farms and maximum attainable yields from research stations. We conclude that agronomy and policies are likely to be the reasons for these large yield gaps. A key challenge to be addressed in closing the yield gaps is that of replenishing and properly managing soil nutrients.

Keywords Actual yields · Cameroon · Crop suitability · Fuzzy set · Maximum attainable yields · Soil nutrients · Yield gap

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INTRODUCTION

It is estimated that present global agricultural production must increase by 70–100 % to feed over 9000 million people by 2050 (Dubois 2011). It is forecast that the world will suffer a slowdown in the annual growth of crop production, from 2.2 to 1.1 % globally, and from 3.0 to 1.2 % in developing countries from 2006 to 2050 (Bruinsma 2009). Average annual crop yield growth within this period will halve from 1.7 to 0.8 % and from 2.1 to 0.9 %, respectively (Bruinsma 2009). Cameroon, like much of sub-Saharan Africa is undergoing a demographic and economic transformation that stands to change the quantity and types of food demanded (Thornton et al. 2011; Tilman et al. 2011). With an annual population growth rate of about 2.8 % and an urbanization rate of 52 % in 2010 (INS 2010), food production is likely to face numerous challenges, including in particular competition for land with other uses, an increase in the total amount of food demanded, and changes in dietary preferences. Such transformations have lately been witnessed in Asia and Latin America following the growth of the middle class in recent decades (Satterthwaite et al. 2010). Food production in Cameroon is still largely in the hands of small-holder farmers who make up about 70 % of the farming population (INS 2010). Cultivation practices continue to be characterized by the use of basic tools, small farm size, low capital input, high labor inputs, limited control of plant pests and diseases, and low yields (MINADER 2005, 2006).

The challenges of producing food under such constrained conditions are mounting. One has to question the ability of small-holder farmers to cope with the evermore complex, multi-level, socio-economic factors that have implications on food crop production at the farm scale. The challenge of coping with this dynamically changing socio-economic context is further compounded by global environmental changes

that affect crop yields and food production. Key among them are the impacts of climate change and soil resources degradation (Sanchez 2002; Sasson 2012), which negatively affect the attainment of food security, reduction of poverty, and meeting developmental challenges in the developing world (Thornton et al. 2011; Bindraban et al. 2012; Titttonell et al. 2012). Opinion tends to be converging on the need to increase food production as an important step toward food security in sub-Saharan Africa (De Janvry and Sadoulet 2010; Misselhorn et al. 2012). While this region at present offers the best prospects for global crop land expansion (Bruinsma 2003), one cannot assume that the expansion of agricultural land alone will be sufficient to meet the strong increase in demand for food and fiber in the region. In Cameroon, cropland under different crops has generally been increasing steadily since 1961 (FAOSTAT 2012). Notwithstanding this increase in cropland, food production has not been increasing sufficiently to meet the rising demand (Sasson 2012). Cameroon was therefore not immune to the food price crisis of 2008–2009. The crisis led to several weeks of social unrest (with a total of 40 fatalities officially reported) in Cameroon's main cities (Lagi et al. 2011). There is therefore a serious case for reducing agricultural yield gaps as one of the conditions for meeting the country's food production challenges.

An assessment of the actual level of crop yields against maximum attainable levels is important for agricultural policy development and resource planning (Bruinsma 2009). It offers an important insight into the performance of agriculture and the potential for yield growth and expected productivity gains that can be exploited by agricultural investments and policies. It also offers opportunities for exploring different options for narrowing the yield gap for specific biophysical and socio-economic circumstances. Understanding the extent to which biophysical constraints contribute to explaining the yield gap informs policy not only on the spatial distribution of biophysical productivity constraints but also re-energizes efforts toward focusing on non-biophysical contributors to low productivity. Where biophysical constraints are less of an important factor in determining the yield gap, issues of farm management, farming patterns and practices, as well as agricultural policy are likely to be contributing factors to low productivity. In Cameroon, the diversified climate offers immense potential for the development of a wide range of crop production systems (Westphal et al. 1985; de Graaff et al. 2011; Yengoh et al. 2011). Farming practices, however, have not been generally effective in conserving and ameliorating soil nutrients (MINLAPDAT 2005; Kanmegne 2006) hence soil fertility decline has been reported as an important problem of food production in the country (Kanmegne 2006). Is this likely to be an important leverage point for addressing the problem of large yield gaps for food crops? Such information can serve both as a gauge of the need for development in the field of agricultural extension as well as a guide to the allocation of

resources for development in the sector. Local level analysis of constraints to food crop production can guide the development of carefully targeted responses that are adapted to local realities (Lobell et al. 2009; Bindraban et al. 2012).

The goal of this study is to quantify yield gaps for major food crops in Cameroon. To achieve this aim, it quantifies the biophysical suitability, and assesses the general trend of yields for these food crops over the last century, using linear regression. The significance of differences between actual yields and maximum attainable yields is estimated using statistical tests. Finally, key challenges of closing the yield gap based on the chief constraints relevant for Cameroon and much of sub-Saharan Africa are discussed.

Terminologies

Potential yield is defined as that which is determined by the amount of incident solar radiation, CO₂ concentration, temperature, and plant density for a given crop variety or hybrid in a specific growth environment (Cassman et al. 2003). Limitations to the attainment of this optimum potential yield could result from changes in natural determinants of crop productivity such as rainfall variability, nutrient decline, pest infestation, and weed invasion (Cassman et al. 2003). Perfect management of these limitations is not possible, even under the best managed conditions (Lobell et al. 2009). This makes the estimation of potential yield possible only through using crop models that assume perfect management of all yield-reducing factors (Lobell et al. 2009). *Maximum attainable yields* are yields derived in yield experiments in agricultural research stations, under the best management conditions currently known and applicable for any given crop growth environment. This is because under such controlled experimental conditions, most of the management limitations on the achievement of maximum attainable yields are controlled. Most farmers (especially those in developing countries) can afford neither the financial and material resources nor the technical expertise to effectively manage limitations to the attainment of yield levels comparable to experimental states. Their yields are therefore likely to be below maximum attainable levels and are termed *actual yields* (Cassman et al. 2003), or average farmer yields (Lobell et al. 2009; Nin-Pratt 2010). The *yield gap* is the difference between maximum attainable yield and actual yield.

MATERIALS AND METHODS

Study Area

Cameroon lies in sub-Saharan Africa, located on the Gulf of Guinea (Fig. 1), between latitudes 1.7°N–13.8°N and

longitudes 8.4°E–16.8°E. It has five major agro-ecological zones: the inland equatorial forest; maritime equatorial forest, highland tropical, Guinea-savannah, and Sudan-savannah. These zones represent a majority of the agro-ecological zones within which small-scale food production is practised in sub-Saharan Africa. Being a dominant sector of the national economy, agriculture currently contributes about 52 % to GDP, 45 % of export earnings, and 15 % in public revenue (INS 2010). Reducing or closing the yield gap therefore has both a strong economic and social incentive. Also very important in most developing countries is the point that closing the yield gap has the potential to generate multiplier effects for growth and the development of economic opportunities in the rural off-farm sector (Kidane et al. 2006).

Data for Biophysical Crop Suitability Modeling

Input data for modeling biophysical suitability is derived principally from Geonetwork spatial databases, maintained by the Food and Agriculture Organization of the United Nations (Table 1). The methods used to derive, analyse, and present the soil properties of the FAO-UNESCO Soil Map of the World are comprehensively presented in Nachtergaele et al. (2008).

Biophysical Suitability Modeling

A spatial suitability model is used to map out the biophysical suitability of different crops. The model uses fuzzy logic to combine different climatic, soil, and geomorphological variables that determine suitability (Fig. 2). Fuzzy membership functions provide a measure of the degree of similarity of an element to a fuzzy set (Bonham-Carter 1994). Membership to the set is expressed on a continuous scale from 1, representing full membership, to 0, representing full non-membership (Bonham-Carter 1994; McBratney and Odeh 1997). McBratney and Odeh (1997) define this relationship mathematically as:

$$A = \{x, \mu_A(x)\} \quad \text{for each } x \in X,$$

where μ_A is the membership function that defines the grade of membership of x in A .

The membership function $\mu_A(x)$ takes values between and including 1 and 0 for all A . For continuous data such as temperature, rainfall, soil nutrients, slope, and elevation, fuzzy set theory is seen to be a more appropriate method for computing their variation over space than traditional crisp classifications using Boolean algebra (Bonham-Carter 1994). Fuzzy membership functions can take many forms (Bonham-Carter 1994; McBratney and Odeh 1997; Raines et al. 2010). However, there are some standard forms that are commonly used for a range of practical applications.

Six of the functions described by Raines et al. (2010) are used for computing crop suitability in this study (Fig. 2). They include fuzzy large, small, near, Gaussian, linear and Gamma (Raines et al. 2010).

Fuzzy Gamma overlay operations are used to combine membership values for two or more datasets. Different types of overlay operations, their strengths and weaknesses are explained by Bonham-Carter (1994). Bonham-Carter (1994) describes fuzzy Gamma as a good overlay method which offers a flexible “compromise between the increase tendencies of fuzzy algebraic sum and the decrease tendencies of fuzzy algebraic product.” Mathematically, Raines et al. (2010) define fuzzy algebraic sum as

$$\mu(x) = 1 - \pi_{i-1}^n(1 - \mu_i)$$

Fuzzy algebraic product is defined as:

$$\mu(x) = \pi_{i-1}^n \mu_i$$

The Gamma operator allows for “increase” and “decrease” combinations of the membership values, yielding output that ranges between the extremes of 0–1. The outcome of fuzzy algebraic sum is increase, where the output is always larger than, or equal to, the largest contributing membership value. On the other hand, the outcome of fuzzy algebraic product is decrease, meaning that the output is always smaller than, or equal to, the smallest contributing membership value. The gamma (exponent γ) is a value from 0 to 1 which allows optimization of the membership combination. Setting it to the extremes of the interval gives either fuzzy algebraic sum ($\gamma = 1$) or fuzzy algebraic product ($\gamma = 0$). Fuzzy Gamma combines fuzzy algebraic sum and fuzzy algebraic product as follows:

$$\mu(x) = (\text{Fuzzy Sum})^\gamma - (\text{Fuzzy Product})^{1-\gamma},$$

where γ is a user-defined input.

The criteria used to define suitability thresholds for different crops (Table S3 in Electronic supplementary material) are derived from literature sources on tropical agriculture. Comprehensive data on soil suitability guidelines for a range of tropical crops is available for most agro-ecological conditions (Kowal and Kassam 1978; Landon 1984). It is complemented by soil and climate suitability definitions for tropical crops (Bowen and Hollinger 2002; Verdoodt and Van Ranst 2003). For each crop the suitability factors were grouped into soil factors (soil moisture storage capacity, soil texture, soil pH, soil depth, soil nitrogen, cation exchange capacity, and soil organic matter content); climate factors (temperature, rainfall, and length of growing period); and topographic factors (altitude and slope). When assessing the suitability of factors within individual groups, different weights were assigned to each dataset within the group. The importance of each factor in the suitability of an area for a particular crop is

Fig. 1 Land cover in Cameroon. The locations **i** refer to the location of IRAD research stations from which maximum attainable yields are derived. Bamili supplied data for potato, cassava, and maize; Ekona supplied data for sweet potato and beans; Maroua supplied data for rice, groundnut, and sorghum

informed by agronomic literature (Kowal and Kassam 1978; Landon 1984; Bowen and Hollinger 2002; Verdoodt and Van Ranst 2003). For each crop, factors with strong influence on

the suitability are given a weight of 0.8, those with weak influence are given a weight of 0.25, while those with no clear strong or weak influence are given weights of 0.5. When

Table 1 Characteristics of data used in crop suitability modeling. All the datasets can be accessed online at the FAO-Geonetwork geospatial database: <http://www.fao.org/geonetwork/srv/en/main.home>

Data	Date published	Type and resolution	Source
Organic carbon pool—topsoil (0 to 30 cm)	2007-02-13	5 * 5 arc minutes Grid	“Derived Soil Properties” of the FAO-UNESCO Soil Map of the World (Nachtergaele et al. 2008)
Soil moisture storage capacity (mm m ⁻³)	2007-02-16		
Cation exchange capacity (soil)—topsoil (meq 100 g ⁻¹)	2007-01-31		
pH—Topsoil (−log[H ⁺])	2007-02-16		
Soil texture (classes)	2000-05-01		
Soil depth (m)	2007-02-16		FAO—Agrometeorology Group
Soil nitrogen—subsoil (%)	2007-02-13		
Monthly air temperature (°C)	2002-08-07	0.05° * 0.05° Grid	
Monthly rainfall (mm)	2008-12-04	1.0° * 1.0° Grid	USGS/EROS Data Center
Length of growing period (days)	2007-02-16	5 * 5 arc minutes	
Altitude (meters above sea level)	2006-05-16	30 arc second Enhanced SRTM-GTopo30	
Slope (%)			

combining the groups resulting from the initial combination of individual factors, all groups carry equal weights. The biophysical suitability of crops is divided into 5 categories based on percentage of suitability: 0–20 % = unsuitable, 21–40 % = minimally suitable, 41–60 % = averagely suitable, 61–80 % suitable, and 81–100 % = very suitable.

National Crop Yield Trends

Analysis of time-series trends is performed on nationwide annual average yields for eight different crops. The goal is to investigate the overall direction of the trend of food crop yields for the country as a whole. Time-series data from crop yield summaries for Cameroon are obtained from the Food and Agriculture Organization (FAOSTAT 2012). Linear regression of crop yield on years is performed for the period 1960 to 2010.

Maximum Attainable Yields (Y_m)

Experimental data was derived from three research stations (Fig. 1). The Institute of Agricultural Research for Development (IRAD) is a public administrative institution under the technical supervision of the Ministry of Scientific Research and Innovation. IRAD has five main stations around the country in each of the major agro-ecological zones. It undertakes scientific and technical research on most aspects of agricultural production, with the goal of providing necessary expertise and resources for the development of national agriculture and food production. The yield data used in this study was derived from advanced yield development stages (the 4th and 5th stages in Table S1 of Electronic supplementary material).

Actual Yields (Y_a)

In Cameroon, data on agricultural production (crops cultivated, area under different crop types, and yields) is compiled at the third level administrative units by regional services of the Ministry of Agriculture and Rural Development. The data is gathered by the Divisional Delegations of Agriculture through interviews of randomly sampled farmers at the third level administrative zones. This data is then compiled for second level administrative zones at the Regional Delegations of agriculture before being transmitted to the Bureau of Agricultural Statistics at the national Ministry of Agriculture. At the national level, the raw data from third and second level administrative zone are available when the national aggregation is being performed. The data are then compiled into annual reports by the *Direction des Enquêtes et Statistiques Agricoles* (DESA). The most recent of these reports present mean yields of crops for all farmers in these 58 administrative units in the 2007–2008 farming seasons (MINADER 2010). The actual yield of the farmers is derived from this nationwide dataset. Actual yields for third level administrative zones where the experimental stations are found are used to compare with yields for each experimental station. Each of the experimental stations is located in a different agro-ecological zone, and works in the development of crops that are specific for that agro-ecological zone (Fig. 1). This permits a more extensive appreciation of crop distribution and yield performance across different social and ecological landscapes. Also, the year 2007–2008 can be considered to be a normal year in terms of agricultural production in Cameroon given the absence of major droughts or floods. Finally, since it is a state institution that operates within international guidelines for agricultural

Fig. 2 Membership functions implemented for the biophysical suitability modeling

data collection (Kamgaing 2009), handling and reporting, it is assumed that this data is of good quality.

The choice of crops for the study was based on their importance as a food and income source in Cameroon. Four of these crops are also very important in terms of total production (FAOSTAT 2012) and their contribution to international food security. These are maize (*Zea mays*), rice (*Oryza sativa*), cassava (*Manihot esculenta*), and potato (*Solanum tuberosum*). Other crops important in the

Cameroon context are kidney bean (*Phaseolus vulgaris*), groundnuts (*Arachis hypogaea*), sorghum (*Sorghum bicolour*), and sweet potato (*Ipomoea batatas*).

Comparing Maximum Attainable Yields and Actual Yields

An unpaired *t* test is used to compare the means of maximum attainable yields (Y_m) with those of actual yields (Y_a).

The t test investigates the likelihood that the difference between the means of the two groups could have been caused by chance. The F ratio is used to determine statistical significance. The null hypothesis specifies that the means of maximum attainable yields are equal to the means of actual yields. The alternative hypothesis on the other hand states that the mean of the maximum attainable yields are greater than those of the actual yields. Hence:

$$H_0 : Y_m = Y_a$$

$$H_a : Y_m > Y_a$$

The overall normality of the data is tested using the skewness, kurtosis, and omnibus normality of residuals (Dodge 2008; Rogerson 2010). Before testing for the normality of residuals, the data is normalized using a logarithmic transformation.

Data on Experimental Fertilization and Management

Data on experimental fertilization and management is derived from the Testing and Liaison Unit (TLU) of IRAD, Ekona (Fig. 1). The data shows the response of maize to fertilization under different conditions. These conditions include: differences in variety, differences in amount of one macronutrient (phosphorous) for a given amount of another macronutrient (nitrogen), and differences in varieties for different soil types. The results of this data on experimental fertilization and management are used to explore the effects of nutrient management on yields.

RESULTS

Biophysical Suitability of Crops

The biophysical suitability for five of eight crops (with the exception of rice, sorghum, and potato) tends to decline northwards (Fig. 3) mainly due to decreasing rainfall and shorter growing periods. It therefore follows that for crops that are cultivated nationwide (groundnut, maize, sweet potato), biophysical conditions in the northern regions contribute to low yields. This is also true for a crop such as bean which is not cultivated nationwide. While it is cultivated in northern regions with low suitability, there are areas in the south and east of the country which are suitable for bean, but are not being cultivated (Fig. 3). Cassava cultivation largely follows regions of suitability that is either average or above.

Suitability for some crops is geographically more restricted and is exploited to different degrees. Sorghum is minimally suitable in the drier eastern interiors and up to averagely suitable in regions of the north. However, cultivation is limited

to regions of the north and north west of the country. Potato cultivation is restricted to the Western Highlands and regions of the Adamawa Highlands where cooler temperatures and sufficient precipitation combine to provide ideal conditions. Rice suitability and cultivation stand out from the general picture. The distribution of reported rice cultivation largely ties with administrative units where there are limited irrigation schemes favoured by the existence of dams. For five out of the eight crops, >72 % of the area cultivated is either averagely suitable or above average (Fig. 4). The exceptions are rice, sorghum, and potato.

Observed National Crop Yield Trends

The trend of yields for all crops (with the exception of potatoes) has been positive for the 1960 to 2010 period. For beans, this positive trend has been relatively stable and significant (Fig. 5). For other crops (such as maize and sorghum), the positive yield trend is marked by high annual variation. For crops such as rice, cassava, and sweet potato, the generally positive trend of yields hides substantial decreasing trends from 1990 to 2005 (Fig. 5).

Yield Gaps

Notwithstanding the improvements in yields experienced by some crops at the national level between 2003 and 2007, the yield gaps remain relatively large (Fig. 6). For seven out of the eight crops investigated, the maximum attainable yield is significantly higher ($P < 0.05$) (Table S1 in Electronic supplementary material). The exception is beans. The largest differences are for sweet potato and cassava, with yield gaps of 77.5 and 73.1 %, respectively (Table S2 in Electronic supplementary material). The yield gap for rice is 75.0 %. Sorghum, maize, and potatoes have yield gaps of 62.6, 67.2, and 64.0 %, respectively. Comparatively, legumes have the smallest yield gaps, with groundnuts 58.6 % and beans 7.1 % (Table S2 in Electronic supplementary material). Over 55 % of the maximum attainable yield for groundnuts; over 60 % for maize, potato, sorghum; and over 70 % for rice, sweet potato, and cassava remain unattained.

Fertilizer Use and Fertilization Management

While yield response to the use of fertilizer and the number of times of fertilizer application is positive for the two maize varieties (Ekona Yellow and CMS 8501) tested, the response between the use and non-use of fertilizer is highest for CMS 8501 (Fig. 7a). Yield response to increase in P to N use is positive to small rates of N (0 and 20 kg). The increases become less consistent with higher rates of N (40 and 60 kg) (Fig. 7b). However, the use of 60 kg of P at any rate of N gives rise to comparatively high yields. For

Suitability Classes

Fig. 3 Biophysical suitability of different crops (derived from fuzzy spatial modeling) in Cameroon, overlaid with the area cultivated for these crops. The white patches within the maps indicate areas of no data

Fig. 4 Percent of area cultivated for individual crops in different suitability classes

Fig. 5 Yield trends for major roots and tubers, cereals and legumes in Cameroon (1961–2010). For each crop, a linear trend line is fitted, together with a 95 % confidence interval. The yield data is derived from FAOSTAT (2012)

Fig. 6 Actual yields and maximum attainable yields for 8 major crops in Cameroon. *Error bars indicate standard errors*

all soil types (sedimentary sandy loams and lower volcanic soils) and for all maize varieties (CMS 8611, CMS 8608, and Local), positive outcomes are achieved from the use of fertilizers (Fig. 7c).

Figure 7a shows the effects that the time of application of the right type of mineral fertilizers can have on yields under the same farming and biophysical conditions. Figure 7b shows the effects that the rate of application on the other hand would have on yields, all other things being equal. Figure 7 illustrates the importance of farmer education through extension and other information services on yield improvement. Differences in soil types give rise to significant yield differences (*t* test, $P < 0.05$) between the same varieties of maize grown with the same treatments within the same agro-ecological zone (Fig. 7c).

DISCUSSION

A number of factors can be used to explain different aspects of the yield gap in Cameroon. Variation in the productivity of different crops over time can partly be attributed to changes in government policy for agricultural support (García-Ponce et al. 2012). Also, one can draw from the situation of nutrient balance in agricultural systems in sub-Saharan Africa in general, and Cameroon in particular, to partly explain the productivity condition for food crops. Finally, the situation of access to nutrient inputs through local, regional, and international markets, as well as input prices can be used to explain the difficulty in increasing productivity among small-scale farmers in Cameroon.

Biophysical Suitability and Crop Production in Cameroon

Cameroon's diversity of agro-ecological zones permits it to host three main farming systems dominating most of the sub-Saharan African region. These are forest-based, tree-crop based, and cereal-root crop-based farming systems (de Graaff et al. 2011). Cameroon therefore has a range of 23 major crops, one of the greatest in Africa (Westphal et al. 1985). Most countries around the Sahel and Sudan-Sahel have only about 12 (Westphal et al. 1985; de Graaff et al. 2011). Nevertheless, all parts of the country do not necessarily provide suitable biophysical conditions for the production of all crops being cultivated by its small- and medium-scale farmers (Figs. 3, 4). For a crop such as potato, its cultivation beyond the limited area of its biophysical suitability is motivated by the readily available internal market for this produce. Market access and a good price are therefore economic motivations for the cultivation of potato. For other crops such as rice, their cultivation is possible in areas where dams and rivers provide opportunities for the development of small-scale irrigation schemes to meet the water needs for paddy rice production. Sorghum is the staple food for most populations of Cameroons three northern administrative regions. The cultivation of this crop is therefore driven by a tradition of sorghum consumption. Hence irrespective of the biophysical suitability for the cultivation of this crop, households still find it a priority food crop in their cultivation mix.

Generally, the cultivation of most crops occur where the biophysical suitability is either average or above average. The yield gaps for such crops are therefore more likely to

Fig. 7 Impact of farm management on the effectiveness of inorganic fertilizer use on maize yields (t ha⁻¹). **a** The effects of N–P–K time of application. **b** Effect of rate of application of nitrogen and phosphorus fertilizers. **c** Effects of local differences (soil types) in locations of the South West Region. Data is derived from the Testing and Liaison Unit (TLU), IRAD Ekona

be attributed to factors of agricultural management than biophysical suitability. For cases where biophysical suitability is not conducive for the cultivation of particular crops, farmers have the added challenge of providing resources to counter the challenges brought about by and unsuitable biophysical production environment.

For crops that are cultivated in areas of average or higher biophysical suitability, the removal of government support between 1985 and 1990 had limited effects on the overall trend of yields. Such crops include bean, sweet potato, and maize (Fig. 5). As farmers adjusted to new production realities, and as new government support was introduced after 2000, yields for such crops have responded with noticeable increases to pre-Structural Adjustment (SAP) levels (Fig. 5). Rice stands out as the exception in this analysis. Being a crop that is cultivated dominantly in areas of low biophysical suitability, the yield of rice has failed to recover from the decreases consequent on the removal of government support since 1990 (Fig. 5). The high growth of rice yields up to the mid-1980s was achieved through substantial government support for production through a number of state companies. While far fewer small-scale farmers continue to cultivate rice in areas close to dams which provide limited irrigation at or near these former government structures, reviving rice production to reach pre-SAP yield levels would require greater levels of investments that counteract the low biophysical suitability.

Agricultural Policy and Yield Changes Over Time

The importance of biophysical suitability of crops in contributing to the yield gap becomes evident when the time series of yields (Fig. 5) is examined within the framework of governmental support or non-support for agriculture in Cameroon. In many analyses of agricultural productivity and development in Sub-Saharan Africa, the period between the late 1980s and the end of the 1990s is highlighted as a reference period for assessment of differences (Kidane et al. 2006). It is the period of the World Bank and International Monetary Fund (IMF) sponsored SAPs. Some of the key features of the SAPs included a focus on export-led growth, privatization of state-owned companies, economic liberalization, and movement toward attaining economic efficiency on free market principles (Thiele 2002). The SAPs led to significant reduction of support for agriculture by reducing access to agricultural extension services for small-scale farmers and eliminating input subsidies (Tchoungui et al. 1995; Thiele 2002).

Since 2000, government support to agriculture has increased, taking the form of subsidization of inputs such as improved seeds and inorganic fertilizers. There has also been support for financial services which benefit small-scale farmers and farmers' common initiative groups.

Increasingly, government is providing farmers with information on market trends and prices for food crops in accessible urban markets so that farmers can get the most income from their produce. By 2005, a broad-based strategy was launched to guide the country toward the attainment of agricultural development. This strategy is made up of a group of projects designed to address key issues considered as key constraints to agricultural productivity in Cameroon. Three projects in this strategy directly address issues regarding narrowing the yield gap (MINADER 2006). These include:

1. The *Support Project for Agricultural Mechanization* (known in its French acronym as PAMA) has the overall objective of increasing the productivity of food crops and increasing the acreage of small farms by promoting agricultural mechanization. To achieve this goal, PAMA will have to improve access of small- and medium-scale farmers to small equipment and agricultural machinery; facilitate the acquisition of production equipment through loan schemes; and propagate the use of suitable equipment.
2. The *Support Programme for the Production and Distribution of Seeds and Planting Material* is in charge of medium- and large-scale farmers with the development of supervised seed production farms. This project therefore promotes private investment in seed production farm; facilitates support for financing seed production; supervises the quality of seeds produced by trained farmers and ensures that produced seeds reach desired rural communities through appropriate distribution and marketing channels.
3. The *Project for the Management of Agricultural Soils* has as main objective, the conservation of soils through erosion control. To achieve this objective, this project will begin by developing a more detailed cartography of available soil resources, and then investigate and recommend appropriate conservation strategies that have the potential of contributing to the long-term fertility of soils.

It must be noted that there are many other projects that can indirectly contribute to agricultural productivity increase within the national strategy. These are projects that contribute to improvements in communications infrastructure, market access, the empowerment of farmers' common initiative groups, extension services, and others (MINADER 2006). While the national strategy has been implemented since 2005, no assessment has been made to evaluate the impacts of this strategy on increasing agricultural productivity. Local unverified reports, however, claim that yields have noticeably increased for some crops. For example, local government officials claim that yields for maize have increase from a mean of 1.1 tons ha⁻¹ to

1.9, and potato from 10 to 23 tons ha⁻¹ from 2005 to 2010, respectively.

In the yield time series (Fig. 5), this period is marked by leaps which represent a response to such proactive policies. Beans (which demonstrate steady growth over the entire time series) witnessed yield increases of >40 %, while cassava and groundnut yield improved by >100 % (Fig. 5). While evident in other crops such as sorghum, these yield increases were not equally impressive. Maize did not benefit from such growth at a national scale, notwithstanding significant efforts by government to promote this crop. The increases from 2003 to 2007 demonstrate the possibilities that can be nurtured for yield gain in Cameroon's agriculture.

One must note that the yield data reported in the database of agricultural statistics of the Food and Agriculture Organization defines yield as harvested production per unit of harvested area for crop products (FAOSTAT 2012). Yield data (in most cases) are not recorded but obtained by dividing the production data by the data on area harvested. This data is less reliable for permanent crops than it is for temporary crops (FAOSTAT 2012). The constant yields for cassava for over two decades in the time series is therefore likely to be less reliable (Fig. 5) as there probably is no data for these years for this crop. This is because cassava is a crop that has no fixed planting and harvesting time for a geographically varied country like Cameroon. This may even hold true for other temporary crops showing shorter periods of constant yields in the time series such as bean, groundnut, and sweet potato (Fig. 5).

Nutrient Imbalance in Agricultural Systems and Crop Productivity

Soil fertility decline in Cameroon has been attributed to poor management practices in small-scale agricultural systems (Amujoyegbe et al. 2010; Kombiok et al. 2013). These have been blamed for nutrient decline and yield decreases for many crops in the country (Kombiok et al. 2013). Nutrient amendments can contribute to boosting yields across varieties, and soil groups in Cameroon (Fig. 7). Annual variation in crop yields can therefore be explained by either biophysical or policy factors. Crop yield and food production in agriculturally poor soils that are not substantially dependent on fertilizer inputs or other additives varies greatly from one agricultural region and soil to another (Azam-Ali and Squire 2002). The changing role of different agricultural policies within which smallholder food crop production is carried out also affects yields and total production. It has been observed that in Cameroon, productivity increases are mainly constrained by a lack of improved varieties, limited use of fertilizer amendments on agricultural soils, poor management of

agricultural soils and water and resulting declining soil fertility (MINLAPDAT 2005; Henao and Baanante 2006).

The importance of fertilization and management can be appreciated by comparing the yields in Cameroon with yields in similar agro-ecological zones in sub-Saharan Africa. Under improved cultural practices, per hectare yields of 3.5 tons for sorghum (Amujoyegbe et al. 2010), up to 7.5 tons for rice (García-Ponce et al. 2012), and >3 tons for groundnuts (Kombiok et al. 2013) can be expected in the Guinea- and Sudan-savannah agro-ecological zones of West Africa. With improvements in varieties and enhanced soil fertility management, yields 21 tons ha⁻¹ are reported for roots and tubers such as cassava, sweet potato, and potato (Fermont et al. 2009). In Malawi, using land management by perenniation (the integration of trees and perennials into fields of food crops), small-scale farmers are able to achieve yields of >4 tons ha⁻¹ and still attain good levels of soil conservation (Glover et al. 2012). This constitutes a quadrupling of average yields for farmers prior to use of this integrated land management practice. Such differences suggest that yields for major food crops can be doubled and even tripled when the right combination of policies are implemented and sustained in support of agriculture. Achieving such productivity gains would also entail increased costs of inputs (including labor and time) and crop management.

Like other countries in the sub-region, high rates of nutrient mining and low levels of replenishments have created large deficits of micro- and macronutrients on agricultural soils (Sánchez 2010; Sasson 2012). It is for this reason that the need to improve soil health has been advanced as one of the key biophysical measures in addressing the yield gap (Lal 2006; Tittonell et al. 2012). Comparisons have been made between production systems of similar radiation environment, with soil fertility and water inputs as key factors determining differences of yields. Such comparisons conclude that differences in yields between smallholder single season production systems in the African Sahel and perennial plantations of the same grain crops in South East Asia can be as much as 100-fold (Azam-Ali and Squire 2002). A combination of low N and P in the soil, as well as low rainfall or limited irrigation is responsible for seriously restricting yields in sub-Saharan Africa (Sanchez 2002; Lal 2006; Tittonell et al. 2012). While low levels of soil N and P are nationwide problems owing to high deficits of nutrient balances (de Graaff et al. 2011), the importance of low rainfall as a significant constraint to yields is limited to the areas of the country north of latitude 7°N where the length of the growing period is <240 days (Yengoh et al. 2011). In areas south of latitude 7°N, the growing period is long enough to sustain most of the cultivation of crops commonly

consumed and traded in these agro-ecological zones, although for single seasons in some cases (Yengoh et al. 2011).

Market Constraints to the Use of Inorganic Fertilizers

The adequate use of inorganic fertilizers is seen to be an important means for boosting soil nutrient status (Fermont et al. 2009) and increasing the productivity of food crops. In sub-Saharan Africa, market constraints of limited infrastructure for transportation, delivery, and storage, as well as high costs of inorganic fertilizers limit small-scale farmers from taking advantages of this technology (Godfray et al. 2010). In Cameroon, the annual average consumption of fertilizers is about 6 tons per 1000 hectares of arable land, compared to 12 tons as an average for sub-Saharan Africa, 47 tons in Australia, 215 tons in France, and 111 tons in the USA (WTO 2007). This low level of use can be attributed to the high cost of mineral fertilizers. Imports of agricultural products are subject to an import duty of 24.5 % and 19.25 % value added tax (WTO 2007). Besides such high importation and tax costs, the infrastructure for handling, storage, and distribution of mineral fertilizers is very poor and serves to add to the already high transaction costs for fertilizers purchase and delivery. Nonetheless, in the national strategy for the development of agriculture and the rural sector, boasting current low levels of inorganic fertilizer consumption is seen as a key precondition for narrowing the yield gaps for both food and cash crops in Cameroon (MINLAPDAT 2005).

It must be noted though, that access to the right quantity and quality of fertilizers may not immediately translate to higher yields for most small-holder farmers. Many other issues of farm management have to be addressed to ensure that the right mineral fertilizers are applied in the right amounts, at the right time, and under appropriate soil, water and crop conditions. Yields can be substantially improved if interventions are provided in carefully designed packages that address constraints for the cultivation of particular crops or crop combinations under specific local or regional conditions. The importance of designing local scale or location-specific intervention packages in addressing problems of low yields is exemplified in Fig. 7a, b, and have been urged in some studies (Bindraban et al. 2012; Krawinkel 2012).

Potential for Addressing the Yields Gap Through Other Fertilization Options

While many constraints persist with regard to the affordability and use of mineral fertilizers by smallholder farmers in much of Cameroon and sub-Saharan Africa, mineral

fertilizers remain the quickest means of amelioration of the soil's macronutrients (especially phosphates) and boosting yields above the most meager levels (Fussell et al. 1987; Bationo et al. 1989; Bekunda et al. 1997). The high cost of mineral fertilizers does necessitate the search for more affordable sources of fertilization for small-scale farming systems in sub-Saharan Africa. Organic fertilizers such as manure, compost, worm casting, and slurry have the potential to supply the necessary nutrients to boost yields among small-holder crop producers in Africa (Krawinkel 2012). The use of organic fertilizers can have a number of advantages for cropping systems in Cameroon where many of the soils are heavily depleted of macronutrients, have low organic matter content, and generally low fertility (Kanmegne 2006). Carefully designed and managed organic systems of fertilization have the potential of increasing soil fertility and biodiversity (van Schöll and Nieuwenhuis 2004; Liu et al. 2009), increasing soil organic carbon pools (Gattinger et al. 2012), increasing humus content, increasing nitrogen availability, and productivity of the soils (Liu et al. 2009).

Notwithstanding the role organic fertilizers can play in improving soil conditions and yields for small-holder farmers in developing countries, they have a number of short-comings. Optimally managed organic systems produce lower yields per hectare than conventional systems under the same constraints (Lal 2006). The potential for long-term soil amelioration, enhanced soil carbon pools, soil biodiversity, and soil structural health are all highly valuable conditions for small-holder farming systems in the country. Added to these, organic fertilization comes with numerous environmental benefits that can improve the sustainability of small-holder farms, including lower greenhouse gas emissions, limited use of pesticides and herbicides, and higher rates of water use efficiencies (Pretty et al. 2003; Liu et al. 2009; Gattinger et al. 2012).

CONCLUSION

Modeling of the biophysical suitability of major food crops in Cameroon demonstrate that most of the common and important food crops are farmed in areas where the biophysical suitability permits such cultivation. Farming areas in the north of the country are generally less biophysically suitable than the majority (south of latitude 11°S). While crop yields per hectare have been generally increasing since 1961, the gap between actual yields and maximum attainable yields remain significantly large for most crops. Given the generally suitable biophysical conditions for the cultivation of the country's most common crops, these large yield gaps can be attributed to agronomy and policy rather than biophysical suitability. Nutrient imbalances in

small-scale agricultural systems represent some of the key constraints that need to be addressed to boost and sustain the productivity of food crops in Cameroon. To meet this challenge, there is need to reduce the imbalances in farm nutrient flows as well as improve access to both organic and inorganic forms of nutrient inputs.

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